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ORIGINAL RESEARCH ARTICLE

First retrospective dosimetric comparison of three radiotherapy techniques for nasopharyngeal carcinoma in Mauritania: 3D-CRT, 3D-CRT+E, and VMAT

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Abstract

Introduction: Radiotherapy remains the primary therapeutic option for nasopharyngeal carcinoma (NPC). The choice of technique, however, directly influences tumor control and the preservation of healthy tissues.

Objective: This study aims to evaluate the dosimetry outcomes of three approaches: three-dimensional conformal radiation therapy (3D-CRT), 3D-CRT with electron boost (3D-CRT+E), and volumetric-modulated arc therapy (VMAT), as implemented at the National Oncology Center in Nouakchott, Mauritania.

Methods: Sixty-seven patients with NPC were included. For each patient, three plans (3D-CRT, 3D-CRT+E, and VMAT) were available or retrospectively reconstructed from archived CT datasets, yielding 201 plans for paired dosimetric comparison. Treatment planning was performed using Eclipse 3.0, with delivery on the Clinac 2100 for 3D-CRT and 3D-CRT+E, and Halcyon 3.0 for VMAT. Dosimetric parameters, including dose coverage (D95%), conformity index, homogeneity index, and doses to organs at risk (OARs), were evaluated. Isodose volumes (ISO30, ISO20, ISO10) were also assessed. Statistical analyses were performed using the Wilcoxon test.

Results: VMAT exhibited significantly higher dose coverage (D95%, $p = 0.01$) and demonstrated optimal homogeneity and conformity ($p < 0.001$) compared to 3D-CRT and 3D-CRT+E. It also reduced radiation exposure to critical OARs ($p < 0.008$) and lowered isodose volumes (ISO30, ISO20, ISO10, $p = 0.0187$), thereby enhancing healthy tissue sparing.

Conclusion: The findings confirm that VMAT offers clear dosimetric advantages over 3D-CRT and 3D-CRT+E, consistent with international evidence. The novelty of this study lies in its demonstration, for the first time in Mauritania, that VMAT can be successfully implemented in routine practice. By validating global standards in a local context, this study supports the integration of VMAT into national treatment protocols and highlights its potential to improve clinical outcomes for patients with NPC.

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1. Introduction

Nasopharyngeal carcinoma (NPC) is a malignant tumor arising from the epithelial lining of the nasopharynx and the upper part of the throat behind the nose. It presents considerable treatment challenges due to its complex anatomical location and aggressive biological behavior.[1,2] The incidence of NPC is notably higher across Southeast Asia, the Middle East, and North Africa. This increased prevalence is associated with etiological determinants, including genetic predisposition, Epstein–Barr virus (EBV) infection, and environmental influences, such as dietary habits and carcinogen exposure.[3,4] In high-incidence areas like southern China, NPC is often detected in late stages, which limits therapeutic options and negatively impacts patient outcomes.[5,6]

However, there is a notable deficiency in the published literature on the epidemiology and treatment outcomes of NPC in Nouakchott, Mauritania. To date, no comprehensive statistical analysis of NPC has been performed in this region. This investigation represents the first effort to provide insights and data on NPC since the initiation of radiotherapy treatment in Mauritania. By addressing this gap, we aim to generate locally relevant evidence to inform clinical decision-making and guide future research.

Radiotherapy remains the cornerstone of NPC management, given the radiosensitivity of the tumor. Because the nasopharynx is situated near critical structures, namely the brainstem, optic nerves, parotid glands, and spinal cord, it necessitates the use of advanced radiotherapy techniques to optimize tumor control while limiting damage to surrounding healthy cells and organs.[7,8] Over the years, several radiotherapy modalities have been developed and refined, including three-dimensional conformal radiotherapy (3D-CRT), intensity-modulated radiotherapy (IMRT), and volumetric-modulated arc therapy (VMAT).[9,10]

In 3D-CRT, computer-generated images are used to construct a 3D-CRT representation of the tumor and adjacent anatomy, enabling targeted radiation delivery. Nevertheless, its limited capacity to conform to the irregular contours of NPC and adequately spare adjacent organs at risk (OARs) has prompted the exploration of more advanced techniques.[11] IMRT offers a major advancement by enabling modulation of radiation intensity within each beam, thereby improving dose conformity and protecting OARs.[12,13] VMAT further enhances this capability by delivering continuously modulated radiation as the machine rotates around the patient, enhancing precision and treatment efficiency.[14,15]

Despite these advancements, comprehensive dosimetric comparisons are essential to determine the relative efficacy and safety of each technique. Previous studies have demonstrated that IMRT and VMAT outperform 3D-CRT regarding target coverage and OAR sparing.[16,17] However, data directly evaluating both clinical outcomes and dosimetric parameters of these modalities for NPC treatment are limited, particularly in diverse clinical settings.[18]

The present work aimed to address this knowledge gap by conducting a comparative dosimetric analysis of 3D-CRT, 3D-CRT+E, and VMAT in 67 NPC patients treated at the National Oncology Center in Nouakchott, Mauritania. By evaluating dosimetric metrics, such as dose coverage (D95%), conformity index (CI), homogeneity index (HI), and doses to critical OARs, this study sought to provide evidence-based recommendations to optimize radiotherapy planning for NPC, ultimately improving clinical outcomes and reducing treatment-related toxicity. To our knowledge, this is one of the first studies of this kind conducted in Mauritania and the surrounding region.

2. Materials and methods

In this retrospective study, archived treatment-planning records were reviewed for patients treated employing two linear accelerators: Clinac (2100, Varian Medical Systems Inc., USA) and Halcyon (3.0, Varian Medical Systems Inc., USA). Treatment plans were generated or retrospectively reconstructed in the Eclipse TPS (3.0, Varian Medical Systems Inc., USA) using archived planning CT datasets. The planning computed tomography (CT) images had been acquired at a 3-mm slice thickness, covering the region from 2 cm above the superior orbital ridge to the aortic arch.[19]

2.1. Inclusion criteria

Patients' data were collected based on the following criteria:

- Confirmed diagnosis: Undifferentiated NPC confirmed by biopsy.
- General health status: Adequate performance status for radiotherapy as defined by the World Health

Organization performance criteria.
- Informed consent: Signed consent for participation and receipt of one of the radiotherapy modalities.

2.2. Treatment protocol

2.2.1. Three-dimensional conformal radiotherapy and three-dimensional conformal radiotherapy with electron boost

To provide context for the applied methodology, the following points summarize the treatment period and technical approach:

- Usage period: Administered between 2013 and 2018 using the Clinac 2100 accelerator.
- Technique details: These techniques involve planning a 3D-CRT dose distribution targeting the tumor volume while preserving OARs. The 3D-CRT+E technique incorporated electron beams to enhance dose precision in specific anatomic regions, thereby reducing exposure to adjacent healthy tissues.[20]

2.2.2. Volumetric-modulated arc therapy

To frame the methodological context, the following points outline the treatment period and the technical principles guiding this approach:

- Usage period: Employed between 2020 and 2023 using the Halcyon 3.0 platform.
- Technique details: VMAT allows for continuous dose delivery with modulation of the beam intensity and shape throughout the rotation around the patient. This technique improves target volume coverage and minimizes doses to OARs by continuously adjusting dose distribution.[21]

Although the 67 patients were initially treated with different techniques (35 with 3D-CRT, 12 with 3D-CRT+E, and 20 with VMAT), all CT scans and planning data were subsequently retrieved from the institutional archives by the Research Department, which was established in 2022. Using these datasets, the missing treatment plans were retrospectively reconstructed so that each patient had three corresponding plans (3D-CRT, 3D-CRT+E, and VMAT). This intra-patient paired design yielded 201 treatment plans and allowed each patient to serve as their own control. By minimizing anatomical variability between groups, this design strengthened the comparison and helped ensure that observed differences were primarily attributable to the radiotherapy technique rather than to inter-patient anatomical variation.

2.3. Dose constraints

Dose constraints were established to maximize the dose to the planning target volume (PTV) while simultaneously minimizing the exposure to OARs. A total dose of 70 Gy was prescribed to the PTV, delivered in 33–35 fractions of 2 Gy over a 7-week period.

The dosimetric goals included the following:

- Ensuring adequate coverage, 95% of the PTV (V95%) received the prescribed dose.
- Constraining maximum and minimum dose fluctuations in the PTV to promote homogeneity.

Maximum and mean dose limits for *OAR*:[19,22]

- The maximum spinal cord dose was restricted to 45 Gy.
- The mean dose to the parotid glands was limited to 20 Gy.
- A maximum dose of 54 Gy was prescribed for the brainstem and optic nerves.
- The maximum dose to the lenses was constrained to 10 Gy.
- A maximum dose constraint of 54 Gy was enforced for the optic chiasm.

Quality indices for treatment plans:

(i) Homogeneity index: HI served as the metric for quantifying dose uniformity across the PTV. This value was calculated using **Equation 1**:

$$HI = \frac{D2\% - D98\%}{D50\%} \quad (1)$$

where D2%, D98%, and D50% correspond to the doses absorbed by 2%, 98%, and 50% of the PTV, respectively. The optimal HI is nearly zero, pointing to dose uniformity throughout the PTV.[22]

(ii) Conformity index: CI measures the extent to which the dose distribution matches the tumor volume shape. This value was calculated using **Equation 2**:

$$CI = \frac{V95\%}{TV} \quad (2)$$

where V95% is the tumor region included within the 95% isodose and TV is the total tumor volume. The ideal CI is close to 1, indicating an excellent match between the irradiated area and the shape of the tumor volume.[23]

2.4. Radiation treatment planning

All patient treatment plans were generated using the Eclipse 3.0 planning system, regardless of the radiotherapy technique used (3D-CRT, 3D-CRT+E, or VMAT).

Simulation images were acquired using a dedicated CT scanner at 3-mm slice thickness, covering the region from 2 cm above the superior orbital ridge to the aortic arch. This provided a precise visualization of the target volume and critical healthy tissues, in particular the brainstem, optic nerves, parotid glands, and spinal cord.

2.4.1. Computed tomography resolution and optimization

The spatial resolution of the CT image used for planning was essential to achieve accurate contouring of target volumes and OARs. CT images were reconstructed at a matrix size of 512 × 512 (pixels) with 3-mm slice thickness, ensuring detailed anatomical visualization.

Volumetric-modulated arc therapy optimization was performed using the Progressive Resolution Optimizer (version 15.6.06). Dose calculation for 3D-CRT and 3D-CRT+E plans was performed using the Anisotropic Analytical Algorithm (version 13.6.23), which is well-suited to complex anatomical configurations, particularly for modeling anisotropic dose diffusion in heterogeneous tissues.

2.4.2. Dose calculation and grid resolution

A uniform dose grid resolution of 2.5 mm was applied to all treatment plans. This fine resolution enabled accurate dose modeling, particularly near interfaces between the target volume and critical OARs.[5,6] The selected dose grid enabled accurate dose calculation and helped ensure appropriate target coverage while limiting OAR exposure.[7]

2.4.3. Beam arrangements

For 3D-CRT, treatment planning involved 3–4 non-coplanar static beams optimized to reduce OAR exposure while ensuring homogeneous tumor volume coverage. For 3D-CRT+E, electron beams were combined with photons to enhance dose conformity in regions requiring precise dose reduction at depth.[8] For VMAT, two full 360° arcs were used. Intensity and beam shape were modulated continuously throughout gantry rotation to achieve high conformity to the target volume.[9]

2.4.4. Dose–volume histograms

Dose–volume histograms were obtained for each patient to visualize dose distribution within the PTV and OARs. In a representative VMAT plan, dose distribution ensured that 95% of the PTV attained 70 Gy, with the average doses delivered to OARs, including the parotid glands and spinal cord, significantly lower compared to 3D-CRT and 3D-CRT+E techniques.[10,11]

2.5. Statistical method

R software (v 4.4.0, R Foundation for Statistical Computing, Austria) was employed for statistical evaluation. Dosimetric parameters, including the median and mean doses received in OAR and target volumes, were calculated. Inter-technique comparisons were conducted using the Wilcoxon test, a non-parametric method suitable for paired, small sample sizes, and non-normally distributed datasets. Statistical significance was assessed to determine meaningful differences among treatment modalities.[24]

3. Results

3.1. Demographic data of patients

Demographic data provide essential insights into population characteristics, including sex, geographic distribution, mortality, and cancer type. The following sections concisely present this data.

3.1.1. Distribution by sex

Within the cohort analyzed, 39 patients (58.2%) were male, and 28 patients (41.8%) were female.

3.1.2. Geographical distribution of nasopharyngeal carcinoma cases and deaths in Nouakchott

This study is a retrospective analysis based on anonymized patient data collected from the National Oncology Center in Nouakchott, Mauritania, between 2013 and 2023.

Figure 1 shows the distribution of cancer cases and associated mortality across different districts in Nouakchott, Mauritania. It illustrates the crude mortality rates observed in this cohort. Because the sample size was limited ($n = 67$) and the data were recovered retrospectively from paper archives, age adjustment was not undertaken. Mortality outcomes were monitored from the initiation of treatment in 2013 through the final data collection in 2023. The median follow-up across the cohort was 18 months, offering a meaningful window for outcome assessment despite the retrospective design.

According to Figure 1, the number of patients and death cases was as follows:

- Toujounin: The highest number of patients (n = 19) with one death, indicating a relatively high incidence but low mortality.
- Dar Naim: 13 patients and three deaths, suggesting a higher mortality rate.
- Arafat: 15 patients and the highest number of deaths (n = 5), possibly reflecting limited healthcare access or quality.

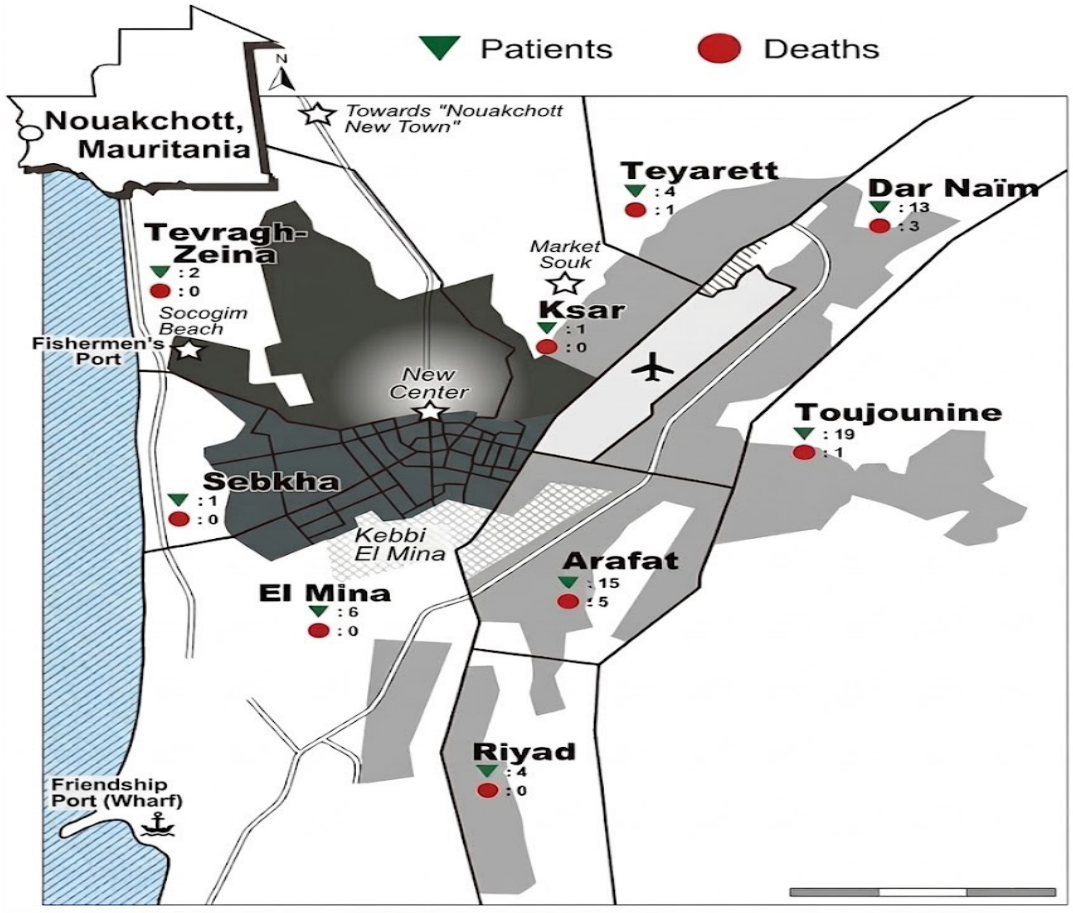

Figure 1. Map of patients and deaths by cancer in Nouakchott

- El Mina and Riyad: Moderate numbers of patients (six and four, respectively) with no deaths.
- Teyarett: Four patients with one death, showing a moderate mortality rate.
- Tevragh-Zeina: Low incidence (n = 2) with no deaths.
- Ksar and Sebkha: The lowest number of patients (n = 1) with no deaths.

3.1.3. Age distribution

Most patients were aged 46–60 years (n = 21, 31%), indicating a higher prevalence of cancer among middle-aged adults. In contrast, the younger (0–15 years, n = 5; 7%) and older (76–90 years, n = 3; 4%) groups had the fewest cases.

3.1.4. Cancer types

Within the study population, undifferentiated carcinoma of nasopharyngeal type (UCNT) was the most frequently observed diagnosis (56.7%), followed by other types of carcinomas (35.8%) and squamous cell carcinoma (7.5%) (Table 1).

Table 1. Cancer types

Type of cancer	Number of patients	Percentage (%)
Undifferentiated carcinoma	38	56.7
Squamous cell carcinoma	5	7.5
Other types of carcinomas	24	35.8
Total	67	100

3.2. Dosimetric results

3.2.1. Dose coverage

Table 2 presents dose coverage (D95%) across the different radiotherapy techniques. The Wilcoxon test was used for statistical comparisons.

The 3D-CRT+E technique slightly improved coverage

compared to the 3D-CRT technique (p = 0.04). A higher median with 3D-CRT+E suggests better coverage for most patients. VMAT significantly improved coverage compared to 3D-CRT+E (p = 0.01), indicating a better dose distribution.

These results confirm that VMAT provides improved dose coverage (D95%) compared to 3D-CRT and 3D-CRT+E techniques. Statistical tests indicated that this improvement was significant for dose coverage (D95%).

3.2.2. Homogeneity and conformity indices

The VMAT technique yielded the highest dose coverage indices (D2%, D50%, D98%, and V95%), indicating enhanced dose distribution compared to 3D-CRT and 3D-CRT+E techniques (Table 3). VMAT also yielded the most favorable HI and CI values, suggesting better uniformity and precision in dose delivery than the 3D-CRT and 3D-CRT+E techniques (Table 3).

No statistically significant variation in homogeneity was observed between 3D-CRT and 3D-CRT+E techniques (p = 0.799). However, VMAT demonstrated a notable improvement in homogeneity relative to 3D-CRT+E (p = 0.008), demonstrating its superior dose uniformity. In terms of conformity, a statistically significant difference was observed between 3D-CRT and 3D-CRT+E (p = 0.03), with 3D-CRT+E offering better conformity. VMAT showed significantly better conformity than 3D-CRT+E (p < 0.001).

3.2.3. Doses delivered to organs at risk

An analysis was conducted to evaluate the doses delivered to OARs across different radiotherapy techniques.

(i) Serial OARs: Table 4 compares the radiation doses received by critical serial organs (spinal cord, brainstem, and optic chiasm) across three different radiotherapy techniques (3D-CRT, 3D-CRT+E, and VMAT).

- Spinal cord: VMAT delivered significantly lower mean (37.93 Gy) and median (38.6 Gy) doses compared to 3D-CRT (mean 48.13 Gy, median

Table 2. Dose coverage (D95%) and Wilcoxon test results

Technique	Mean (Gy)	Median (Gy) (min, max)	Comparison	p-value
3D-CRT	64.42	65.0 (54.8, 69.9)	3D-CRT vs. 3D-CRT+E	0.04
3D-CRT+E	64.96	66.5 (54.6, 68.9)	3D-CRT+E vs. VMAT	0.01
VMAT	67.08	67.5 (64.5, 68.9)	–	–

Abbreviations: 3D-CRT: Three-dimensional conformal radiation therapy; 3D-CRT+E: Three-dimensional conformal radiation therapy with electron boost; VMAT: Volumetric-modulated arc therapy.

Table 3. Dose coverage indices (D2%, D98%, D50%, V95%), mean homogeneity and conformity indices

Technique	D2% (Gy)	D98% (Gy)	D50% (Gy)	V95% (cm^3)	HI (mean)	CI (mean)
3D-CRT	74.5	64.2	69.1	96.5	0.149	1.056
3D-CRT+E	75.0	65.0	69.1	97.0	0.144	1.025
VMAT	75.8	69.2	70.1	98.0	0.094	0.836

Abbreviations: 3D-CRT: Three-dimensional conformal radiation therapy; 3D-CRT+E: Three-dimensional conformal radiation therapy with electron boost; CI: Conformity index; HI: Homogeneity index; VMAT: Volumetric-modulated arc therapy.

Table 4. Dose to serial and parallel organs, Wilcoxon test: Comparison among 3D-CRT, 3D-CRT+E, and VMAT

Organs		Technique	Mean (Gy)	Median (Gy) (min, max)	*p*-value (3D-CRT and 3D-CRT+E)	*p*-value (VMAT and other techniques)
Serial organs	Spinal cord	3D-CRT	48.13	47.1 (0.39, 68)	0.03	
		3D-CRT+E	46.08	46.7 (5.4, 59)		
		VMAT	37.93	38.6 (0.7, 50)		0.001 (3D-CRT+E)
	Brainstem	3D-CRT	59.39	60.2 (1.5, 72)	0.05	
		3D-CRT+E	55.76	56.4 (1.8, 67.7)		
		VMAT	46.37	47.9 (0.7, 58.7)		0.005 (3D-CRT+E)
	Optic chiasm	3D-CRT	43.40	42.83 (30.66, 65.68)	0.04	
		3D-CRT+E	38.28	32.46 (27.14, 56.83)		
		VMAT	32.87	30.66 (21.44, 49.93)		0.002 (3D-CRT+E)
Parallel organs	Right lens	3D-CRT	8.19	6.1 (0.2, 62.1)	0.02	
		3D-CRT+E	5.48	4.2 (0.3, 40.9)		
		VMAT	5.67	5.4 (0.25, 11.6)		0.002 (3D-CRT+E)
	Left lens	3D-CRT	8.50	5.4 (0.2, 55.4)	0.04	
		3D-CRT+E	6.09	4.6 (0.2, 42.7)		
		VMAT	5.11	5.2 (0.2, 10.9)		0.003 (3D-CRT+E)
	Optic nerves	3D-CRT	25.08	23.6 (0.3, 69.03)	0.07	
		3D-CRT+E	28.32	27.3 (0.3, 50.6)		
		VMAT	15.23	15.4 (0.2, 36.9)		0.008 (3D-CRT)
	Right parotid	3D-CRT	46.17	46.8 (1.4, 68)	0.01	
		3D-CRT+E	54.38	53.6 (1.4, 70.3)		
		VMAT	17.88	18.5 (0.75, 45.3)		0.0005 (3D-CRT)
	Left parotid	3D-CRT	47.42	47.5 (0.75, 63.5)	0.03	
		3D-CRT+E	52.17	53.2 (2.0, 67.4)		
		VMAT	16.32	16.7 (0.7, 39.5)		0.002 (3D-CRT)

Abbreviations: 3D-CRT: Three-dimensional conformal radiation therapy; 3D-CRT+E: Three-dimensional conformal radiation therapy with electron boost; VMAT: Volumetric-modulated arc therapy.

47.1 Gy) and 3D-CRT+E (mean 46.08 Gy, median 46.7 Gy).
- Brainstem: VMAT resulted in lower mean (46.37 Gy) and median (47.9 Gy) doses than 3D-CRT (mean 59.39 Gy, median 60.2 Gy) and 3D-CRT+E (mean 55.76 Gy, median 56.4 Gy).
- Optic chiasm: VMAT yielded the lowest mean (32.87 Gy) and median (30.66 Gy) doses, compared to 3D-CRT (mean 43.40 Gy, median 42.83 Gy) and 3D-CRT+E (mean 38.28 Gy, median 32.46 Gy).

(ii) Parallel OARs: Table 4 shows the radiation doses received by the parallel organs (right and left lenses, optic nerves, and right and left parotid glands) using the same radiotherapy techniques.

- Right lens: VMAT (mean 5.67 Gy, median 5.4 Gy) and 3D-CRT+E (mean 5.48 Gy, median 4.2 Gy) delivered lower doses compared to 3D-CRT (mean 8.19 Gy, median 6.1 Gy).
- Left lens: VMAT (mean 5.11 Gy, median 5.2 Gy) delivered the lowest dose, followed by 3D-CRT+E (mean 6.09 Gy, median 4.6 Gy), and then 3D-CRT (mean 8.50 Gy, median 5.4 Gy).
- Optic nerves: VMAT significantly reduced the mean (15.23 Gy) and median (15.4 Gy) doses compared to 3D-CRT (mean 25.08 Gy, median 23.6 Gy) and 3D-CRT+E (mean 28.32 Gy, median 27.3 Gy).
- Right parotid: VMAT (mean 17.88 Gy, median 18.5 Gy) delivered much lower doses than 3D-CRT (mean 46.17 Gy, median 46.8 Gy) and 3D-CRT+E (mean 54.38 Gy, median 53.6 Gy).
- Left parotid: VMAT (mean 16.32 Gy, median 16.7 Gy) provided lower doses compared to 3D-CRT (mean 47.42 Gy, median 47.5 Gy) and 3D-CRT+E (mean 52.17 Gy, median 53.2 Gy).

(iii) Statistical tests: The *p*-values from the Wilcoxon test comparing radiation doses received by various organs between the 3D-CRT and 3D-CRT+E techniques are presented in Table 4. These *p*-values indicated the statistical significance of differences in dose between the two techniques.

- Spinal cord: The analysis yielded a *p*-value of 0.03, denoting statistical significance, with 3D-CRT+E likely providing a lower dose compared to 3D-CRT.
- Brainstem: A *p*-value of 0.05 denotes a difference at the threshold of statistical significance in doses between the two techniques.
- Right lens: A *p*-value of 0.02 implies that 3D-CRT+E results in a significant reduction of radiation to the right lens compared to 3D-CRT.
- Left lens: Similarly, a statistically significant decrease in left lens dose was observed with 3D-CRT+E compared to 3D-CRT ($p = 0.04$).
- Optic nerves: With a *p*-value of 0.07, the comparison of dose between the two techniques failed to demonstrate statistical significance.
- Right parotid: A highly significant *p*-value of 0.01 indicates a substantial dose reduction with 3D-CRT+E compared to 3D-CRT.
- Left parotid: The *p*-value of 0.03 also demonstrates a significant dose reduction with 3D-CRT+E compared to 3D-CRT.
- Optic chiasm: With a *p*-value of 0.04, 3D-CRT+E significantly mitigated radiation dose compared to 3D-CRT.

The *p*-values from the Wilcoxon test, comparing 3D-CRT techniques (either 3D-CRT or 3D-CRT+E) and VMAT for different organs, are provided in the last column of Table 4.

- Spinal cord: A *p*value of 0.001 demonstrates a statistically significant dose reduction achieved using VMAT compared to 3D-CRT+E.
- Brainstem: A *p*-value of 0.005 indicates significantly lower doses with VMAT compared to 3D-CRT+E.
- Right lens: The obtained *p*-value (0.002) demonstrates a statistically significant reduction in radiation dose using VMAT compared to 3D-CRT+E.
- Left lens: Similarly, a *p*value of 0.003 confirms that the reduction in dose with VMAT compared to 3D-CRT+E is statistically significant.
- Optic nerves: A *p*-value of 0.008 indicates significantly lower doses with VMAT than 3D-CRT.
- Right parotid: A highly significant *p*-value of 0.0005 indicates a substantial reduction in dose with VMAT compared to 3D-CRT.
- Left parotid: A *p*-value of 0.002 demonstrates a significant reduction in dose with VMAT compared to 3D-CRT.
- Optic chiasm: A *p*-value of 0.002 shows that VMAT significantly reduced the dose compared to 3D-CRT+E.

(iv) Analysis of isodose levels

Isodoses are contours within the irradiated volume that connect points receiving identical radiation doses. These contours are essential in radiotherapy for evaluating the radiation dose distribution in target tissues and adjacent healthy tissues. Isodoses are often expressed as percentages

of the prescribed dose or absolute units, such as Gy.[25] This analysis focused on three isodose levels: 30 Gy (ISO30), 20 Gy (ISO20), and 10 Gy (ISO10).

Table 5 presents a detailed analysis of the volumes covered (cm^3) in different isodose levels (ISO10, ISO20, and ISO30) for the three radiotherapy techniques: 3D-CRT, 3D-CRT+E, and VMAT. Table 5 compares the mean and median volumes at these isodose levels, highlighting the differences in the target volume coverage and surrounding tissue exposure for each technique.

Comparisons between the 3D-CRT and 3D-CRT+E techniques revealed significant differences in the isodose volumes. For ISO30, the *p*-value was 0.02; for ISO20 and ISO10, the *p*-values were 0.01 and 0.03, respectively. These outcomes indicate that 3D-CRT+E provides better coverage than 3D-CRT. When comparing 3D-CRT+E with VMAT, significant differences were also observed. The *p*-values were 0.03, 0.01, and 0.02 for ISO30, ISO20, and ISO10, respectively, indicating that VMAT offers greater coverage compared to 3D-CRT+E. 3D-CRT exhibited broader high-dose spill into surrounding tissues, while VMAT (Figure 2) demonstrated enhanced conformity, more precisely confining high-dose regions to the tumor volume and minimizing exposure to adjacent healthy tissues. Color-coded isodose lines indicate target coverage and low-dose distribution: 95% (red), 30% (blue), 20% (orange), and 10% (pink). A better conformity of the 95% isodose to the PTV in the VMAT plan (right of Figure 2) compared to the 3D-CRT plan (left of Figure 2) was observed. In the VMAT plan (right), the 95% isodose closely conformed to the PTV, whereas in the 3D-CRT plan, coverage was less precise and accompanied by lateral dose spillage. VMAT also demonstrated a marked reduction in the low-dose bath (ISO30, ISO20, ISO10) surrounding the parotid glands and brainstem. This visual contrast highlights VMAT's ability to generate steep dose gradients, ensuring high-dose delivery to the tumor while minimizing unnecessary dose to adjacent critical OARs.

4. Discussion

4.1. Distribution by sex

Among the study cohort of 67 patients, 58.2% ($n = 39$) were men and 41.8% ($n = 28$) were women. This sex distribution aligns with previous studies reporting a higher incidence of NPC in men. Tobacco, alcohol, and occupational carcinogen exposure are recognized as major preventable determinants of cancer risk, which are more prevalent among men, contributing to this disparity.[25] Similar sex distribution patterns have been observed in studies involving patients with NPC and oropharyngeal cancer.[26,27]

4.2. Geographic distribution and mortality

The most affected regions were Toujounine (28.4%), Arafat (22.4%), and Dar-Naim (19.4%). Notably, Arafat and Dar-Naim exhibited the highest mortality rates, at 33.33% and 23.08%, respectively. To the best of our understanding, few studies have addressed the geographic distribution of NPC in Nouakchott, Mauritania. The elevated incidence and mortality in these regions may be attributed to environmental exposure, healthcare disparities, and socio-economic challenges.[25] Strengthening healthcare infrastructure and ensuring equitable access to advanced diagnostic and treatment modalities may help reduce NPC-related mortality.[26]

4.3. Age distribution

Most patients were between 46 and 60 years old, accounting for approximately 31% of the cohort. This age-related

Table 5. Comparison of isodose volumes across techniques

Technique	ISO30 mean (cm^3)	ISO30 median (cm^3) (min, max)	ISO20 mean (cm^3)	ISO20 median (cm^3) (min, max)	ISO10 mean (cm^3)	ISO10 median (cm^3) (min, max)
3D-CRT	1,449.52	1,325 (432, 3,128)	1,748.00	1,609 (635, 3,424)	2,129.23	2,061 (922, 4,178)
3D-CRT+E	1,638.70	1,604 (376, 2,956)	1,902.31	1,865 (1,120, 4,005)	2,055.17	1,956 (901, 4,956)
VMAT	835.53	820 (162, 2,097)	1,219.16	1,027 (456, 3,096)	1,556.33	1,503.7 (756, 3,504)

Abbreviations: 3D-CRT: Three-dimensional conformal radiation therapy; 3D-CRT+E: Three-dimensional conformal radiation therapy with electron boost; VMAT: Volumetric-modulated arc therapy.

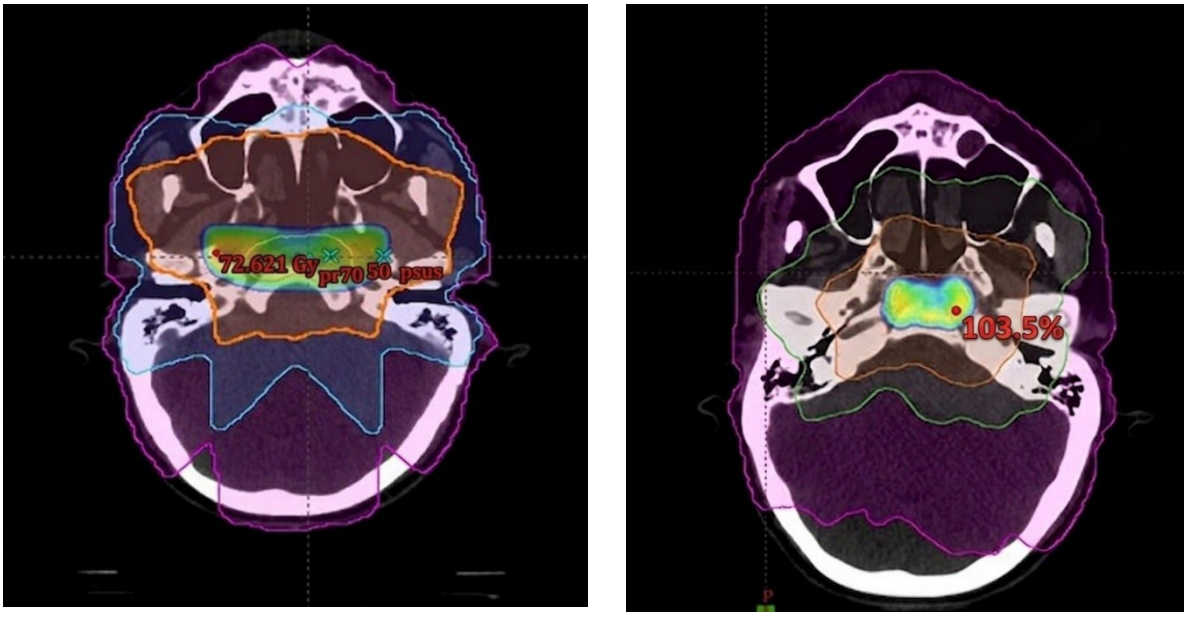

Figure 2. Comparison of dose distribution and isodose lines between three-dimensional conformal radiation therapy (left) and volumetric-modulated arc therapy (right) for a representative nasopharyngeal carcinoma case.

distribution likely reflects cumulative exposure to risk factors and the typically extended latency period of NPC development.[26] Targeted preventive strategies and early detection for this demographic group could contribute to improved prognosis and reduced disease burden. Previous studies have similarly reported increased NPC incidence in middle-aged adults.[25,28]

4.4. Cancer types

The UCNT was the most prevalent histological subtype, observed in 56.7% of cases, followed by squamous cell carcinoma (7.5%) and other carcinoma types (35.8%). The predominance of UCNT is notable and often associated with EBV infection, particularly in Asian and North African populations.[12] Public health strategies, such as vaccination and awareness campaigns addressing EBV-related risk factors, can be implemented to reduce infection rates and mitigate the long-term burden of EBV-associated diseases.[2] This histological distribution is consistent with findings from prior studies.[1,11]

Of the 67 patients, 55 (82.1%) presented with stage 4 disease, exhibiting extensive tumor invasion and nodal involvement, with a mean PTV of approximately 520 cm^3. Ten patients (14.9%) were diagnosed with stage 3, with significant regional lymph node involvement, leading to a mean PTV of approximately 410 cm^3. The remaining two patients (3%) were classified as stage 2, with localized disease and no extensive nodal spread, resulting in a mean PTV of approximately 290 cm^3. The predominance of advanced-stage disease in this cohort reflects delayed diagnostic trends in NPC, commonly observed in low-resource settings, where limited access to early detection and specialized oncology services contributes to later-stage presentations.

4.5. Dose coverage

Dose coverage analysis (D95%) revealed significant improvements with the VMAT compared to 3D-CRT+E. The analysis revealed an improved dose distribution (p = 0.01), with VMAT achieving a mean dose of 67.08 Gy, compared to 64.96 Gy for 3D-CRT+E and 64.42 Gy for 3D-CRT. Enhanced dose coverage with VMAT is associated with improved treatment outcomes and lower recurrence rates, as highlighted by Jiarpinitnun *et al.*[14] Similarly, Mishra *et al.*[29] demonstrated that VMAT offers better target dose coverage and homogeneity compared to other techniques, which translates to better tumor control and reduced toxicity.

4.6. Homogeneity and conformity indices

The analysis of OAR dose exposure demonstrated that different radiotherapy techniques varied in their ability to spare critical structures, influenced by organ-specific anatomical and treatment considerations:

- Spinal cord: VMAT consistently delivered lower doses compared to 3D-CRT and 3D-CRT+E techniques, making it the preferred approach for preserving spinal cord integrity. Minimizing spinal cord dose is crucial

to prevent radiation-induced myelopathy, which can result in paralysis. These findings are supported by Chen *et al.*[30]

- Brainstem: Similarly, VMAT offered better brainstem protection relative to 3D-CRT and 3D-CRT+E, corroborating results from studies by Chen *et al.*[30] and Hu *et al.*[31] The brainstem is highly sensitive to radiation, and minimizing exposure is essential to avoid complications such as brainstem necrosis.[32]
- Optic nerves and chiasm: VMAT achieved improved protection involving the optic nerves and the optic chiasm, reducing the probability of radiation-associated optic neuropathy and vision loss.[33]
- VMAT delivers lower doses to the parotid glands than 3D-CRT and 3D-CRT+E techniques, significantly reducing the risk of xerostomia, a common and debilitating side effect of radiotherapy targeting the head and neck region.[31-35] Chen *et al.*[30] reinforced the evidence of VMAT's enhanced performance in protecting the parotid gland.

The improvement in the CI with VMAT (0.836) compared to 3D-CRT (1.056) represents a meaningful clinical gain. In NPC, where the target volume lies adjacent to the brainstem and optic chiasm, a more conformal plan directly reduces the likelihood of marginal recurrence and late toxicities.

4.7. Isodose levels

The analysis of isodose levels (ISO30, ISO20, and ISO10) revealed significant variations in dose distribution among the VMAT, 3D-CRT, and 3D-CRT+E techniques, which can affect the treatment efficacy and side effects. VMAT significantly lowered the tissue volume exposed to 30 Gy (ISO30), 20 Gy (ISO20), and 10 Gy (ISO10) compared to 3D-CRT and 3D-CRT+E, with *p*-values indicating statistically significant differences. Lower exposure to these doses is needed to minimize the risk of severe side effects, such as fibrosis, necrosis, secondary cancers, and chronic radiation syndrome.[32,34]

Furthermore, Zahu *et al.*'s[35] study on optimizing the prescription isodose level in VMAT for head and neck lesions reported similar advantages. By optimizing the isodose level, Zahu *et al.*[35] demonstrated that VMAT effectively decreases high-dose volumes. This technique improves the treatment effectiveness relative to toxicity by minimizing exposure of surrounding healthy tissues while maintaining tumor control. This is consistent with our findings, as VMAT demonstrated optimal dose distribution and effective sparing of healthy organs by reducing unnecessary radiation exposure.

The VMAT technique also achieved substantial reductions in mean doses to the parotid glands and in maximum doses to the brainstem, often exceeding 20 Gy compared to conventional techniques. These reductions are well above the thresholds identified in Quantitative Analyses of Normal Tissue Effects in the Clinic guidelines as protective against xerostomia and neurological complications, underscoring the clinical importance of these dosimetric improvements.

The significant decrease in ISO30 and ISO20 volumes with VMAT is clinically relevant as well, since limiting low-dose exposure reduces the integral dose to healthy tissues and lowers the risk of secondary radiation-induced malignancies.

5. Conclusion

This comparative dosimetric analysis of 3D-CRT, 3D-CRT+E, and VMAT techniques for treating NPC demonstrated that VMAT offered clear dose distribution, coverage, and organ-sparing advantages. Key findings include:

- Improved dose coverage and homogeneity: VMAT improves D95% and HI, promoting effective tumor control and reducing recurrence risk.
- Enhanced conformity: VMAT provides better CI to the target volume, ensuring precise treatment delivery while minimizing exposure to surrounding healthy tissues.
- Reduced doses to OARs: VMAT achieves lower irradiation of essential OARs, notably the spinal cord and optic nerves, thereby mitigating the risk of major toxicities.
- Lower isodose levels: VMAT decreases the tissue volume affected by high-dose irradiation, further protecting healthy tissues from long-term radiation-induced complications.

Although VMAT is generally preferred, 3D-CRT and 3D-CRT+E may remain suitable options for specific cases, particularly in treating superficial or anatomically shallow tumors. This study emphasizes the importance of selecting an appropriate radiotherapy technique based on the clinical scenario and tumor characteristics to optimize therapeutic outcomes and minimize treatment-related toxicity in NPC management.

The findings of this study highlight the dosimetric advantages of VMAT in the treatment of NPC, yet they remain limited to planning-based comparisons. To translate these results into clinical practice, prospective trials are needed to validate whether the observed improvements in conformity and organ sparing translate into measurable gains in survival, local control, and toxicity reduction. Such

studies would provide the necessary evidence to bridge the gap between dosimetric superiority and patient outcomes.

Beyond clinical validation, future work should also address the economic dimension of implementing advanced radiotherapy in resource-constrained settings. Cost-effectiveness analyses are essential to determine whether the investment in VMAT technology is justified by improvements in patient throughput, reductions in treatment-related complications, and long-term healthcare savings. Evaluating this balance between technological investment and clinical benefit will be critical for guiding policy decisions and ensuring sustainable access to high-quality care.

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Conflict of interest

The authors declare they have no competing interests.

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Ethics approval and consent to participate

In accordance with the regulations of our oncology center (CNO) and national guidelines, the use of anonymized retrospective data does not require Ethics Committee/ Institutional Review Board approval. The authors confirm that all procedures were performed in line with the ethical standards of the Declaration of Helsinki.

Consent for publication

In accordance with the regulations of our oncology center (CNO) and national guidelines, the use of anonymized retrospective data does not require individual consent for publication

Availability of data

No datasets were generated or analyzed during the current study.

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