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Review Article

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Dosimetry of Three-Dimensional Conformal Radiotherapy (3D-CRT) Versus Volumetric Modulated Arc Therapy (VMAT) in Hypopharyngeal Cancer

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ABSTRACT

Objectives: IMRT or VMAT is the standard for curative treatment of hypopharyngeal carcinoma. In our setting, 3D-CRT is widely used due to limited IMRT availability. This study aimed to compare dosimetry between these techniques.

Methods: A retrospective, bicentric study included 30 patients with hypopharyngeal squamous cell carcinoma (15 3D-CRT, 15 VMAT). Prescribed doses were 70 Gy/35 fractions for 3D-CRT and 64–70 Gy for VMAT. Target volumes and organs at risk were analyzed per ICRU 50 standards.

Results: PTV coverage at V95% was comparable. VMAT reduced hot spots (V107%: 0.10% vs 47.46%, $p < 0.001$) and improved dose homogeneity (HI: 0.08 vs 0.81, $p < 0.001$). VMAT also lowered spinal cord maximum dose (40.85 vs 47.40 Gy, $p < 0.001$) and parotid mean doses (left: 28.12 vs 38.01 Gy, right: 28.27 vs 38.57 Gy; $p < 0.05$).

Conclusion: In resource-limited settings, 3D-CRT ensures adequate tumor coverage. VMAT provides better dose homogeneity and spares organs at risk, potentially reducing toxicity and improving quality of life.

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Introduction

Hypopharyngeal carcinomas account for approximately 3 to 5% of head and neck cancers. In Senegal, they are the most common head and neck cancer seen in the ENT department of the University Hospital Center (CHU) of Fann [1,2]. More than 70% of patients present at an advanced stage (III–IV), making radiotherapy, with or without chemotherapy, a key component of curative treatment. However, this treatment requires precise dose delivery while sparing the organs at risk (OARs) [3]. 3D-CRT, a standard technique since the late 1990s, uses fixed beams and multileaf collimators (MLCs). It has gradually been replaced by Volumetric Modulated Arc Therapy (VMAT), a technique derived from dynamic intensity modulation (IMRT) that offers better angular modulation, optimized sparing of OARs, and a more favorable dose gradient [4]. Although several studies, mainly on the oropharynx and larynx, have demonstrated the benefits of VMAT in terms of tumor coverage and protection of the parotid glands and spinal cord, few studies have specifically addressed hypopharyngeal cancer, and to our knowledge, no comparative series of 3D-CRT versus VMAT has been published in Africa [5].

In this context, where head and neck radiotherapy still largely relies on 3D-CRT, this study aimed to compare these two techniques to guide therapeutic decisions. The primary objective was to compare PTV coverage (D95%) achieved with 3D-CRT and VMAT, while the secondary objectives were to analyze the dose delivered to OARs (spinal cord, parotid glands).

Patients and Methods

This was a retrospective, comparative, bicentric study. The study included 15 patients treated for hypopharyngeal carcinoma with 3D-CRT at the Dalal Jamm Radiotherapy Department and 15 others at the Dakar International Cancer Center with VMAT.

The Selection Criteria were as Follows

- Histologically confirmed squamous cell carcinoma of the hypopharynx.
- Prescription of external radiotherapy with curative intent.
- Complete medical records with available dosimetric data.

Patients with a history of cervical irradiation were excluded from the study

Treatment Planning
All patients were immobilized using a 5-point thermoplastic mask. Planning CT scans were acquired with a slice thickness of 2.5 mm
The Target Volumes
(i) GTV (Gross Tumor Volume)
(ii) CTV (Clinical Target Volume)
(iii) PTV (Planning or Treated Target Volume)—as well as the organs at risk (OARs) were defined according to ICRU 50 recommendations, with CTV margins of 5–10 mm and PTV margins of 5 mm [6]. The high-risk PTV (PTV-HR) included the primary tumor and/or metastatic lymph nodes.

Prescriptions
- **3D-CRT:** 70 Gy in 35 fractions (2 Gy per fraction).
- **VMAT**: risk-adapted prescriptions (64–70 Gy) with simultaneous integrated boost (SIB).

Techniques
3D-CRT: 9 to 17 Fixed Beams, Energies 6–10 MV
Two Full Arcs (178–182°), Planning Performed using PINNACLE v16.1.2.

Evaluated Parameters
Target Volumes: V95%, V107%

Homogeneity Index (IH)
3D-RT: IH = (D95%)/(D5%)
VMAT: IH = (D2%-D98%)/(D50%)

D2%: Dose Received by 2% of the Target Volume (Close to the Maximum Dose).
D95%: Dose Received by 95% of the Target Volume (Median Dose).
D5%: Dose Received by 5% of the Target Volume (Median Dose)
D98%: Dose Received by 98% of the Target Volume (Close to the Minimum Dose)
D50%: Dose Received by 50% of the Target Volume (Median Dose)

Conformity Index (IC)

$$IC = \frac{V95\%}{VT}$$

V95% = Volume of the PTV receiving 95% of the Prescribed Dose
TV = Total Treated Volume

OARs: Spinal Cord and Parotid Glands with the following Dosimetric Parameters: Maximum Dose (Dmax) to the Spinal Cord at 45 Gy, and mean dose (Dmean) to the Parotid Glands at 26 Gy.

Statistical Analysis
Quantitative variables were expressed as mean ± standard deviation, and qualitative variables as percentages. For univariate analyses, mean comparisons were performed using the Student's t-test, and proportions were compared using the Chi-square (χ^2) test or Fisher's exact test when at least one expected value was less than 5. Significant treshold was dixed at 0.05.

Results
The mean age of the patients was 45.8 ± 13.4 years (range: 22–68 years), with 41.7 and 49.7 years in the 3D-CRT and VMAT groups, respectively. Female patients accounted for 56.7% of cases (n = 17). The histological type was squamous cell carcinoma in all cases. Most patients had T4a tumors (3D-CRT: 73.3%, VMAT: 93.3%) and stage IVA was predominant in the VMAT group (93.3% vs 80%). The mean tumor volume was comparable: 197.31 cm³ (VMAT) versus 263.64 cm³ (3D-CRT).
The main tumor characteristics are presented in Table 1.

Table 1: Tumor Staging

Classification T	Fréquence (%)		
	Total	RC3D	VMAT
T2	2(6,7)	1 (6,7)	1 (6,7)
T3	3 (10,0)	3 (20,0)	0
T4a	25(83,3)	11 (73,3)	14 (93,3)
Total	30 (100,0)	15(100%)	15(100%)
Classification N	**Fréquence (%)**		
	Total	**RC3D**	**VMAT**
N0	15 (50,0)	6 (40,0)	9 (60,0)
N1	7(23,3)	5 (33,3)	2 (13,3)
N2	7(23,3)	4 (26,7)	3 (20,0)
N3	1(3,3)	0	1 (6,7)
Total	30(100,0)	15(100)	15(100)
Stade	**Fréquence (%)**		
	Total	**RC3D**	**VMAT**
II	1(3,3)	1 (6,7)	0
III	3(10,0)	2 (13,3)	1 (6,7)
IVA	26(86,7)	12 (80,0)	14 (93,3)
Total	30	100,0	100,0

For the planning target volume (PTV), tumor coverage at V95% was similar between the two techniques, but VMAT markedly reduced overdosing (V107%: 0.10% vs 47.46%) and showed better dose homogeneity (HI: 0.08 vs 0.81).

Table 2 Summarizes the Main Dosimetric Results for the PTV, as well as the Conformity and Homogeneity Indices

Table 2: Target Volume Coverage

Variable	Moyenne ± ET		p-value
	RC3D	VMAT	
V107%	47,46 ± 21,60 cc	0,098 ± 0,38 cc	< 0,001
V95%	94,5 ± 2,61 cc	95 ± 5,41 cc	0,755
IC	0,95 ± 0,03	0,95 ± 0,05	0,756
IH	0,81 ± 0,03	0,08 ± 0,04	< 0,001

For the organs at risk, VMAT reduced the maximum dose to the spinal cord (40.85 Gy vs 47.40 Gy) and the mean dose to the parotid glands (28 Gy vs 38 Gy). The dosimetric results for the OARs are presented in Table 3.

Table 3: Dose to Organs at Risk (OARs)

Variable	Moyenne ± ET		p-value
	RC3D	VMAT	
Dmax Moelle épinière (Gy)	47,40 ± 1,81	40,85 ± 1,45	**< 0,001**
Dmoy Parotide Gauche (Gy)	38,01 ± 12,72	28,12 ± 11,79	**0,036**
Dmoy Parotide Droite (Gy)	38,57 ± 9,59	28,27 ± 12,85	**0,020**

Discussion

This dosimetric study shows that both 3D-CRT and VMAT techniques provide satisfactory PTV coverage, with no statistically significant difference in V95% or in the conformity index (CI). In contrast, the VMAT technique offers better dose homogeneity (HI) and improved control of hot spots, with a significantly lower V107%, reflecting a more uniform dose distribution within the target volume . This is supported by several other studies that have demonstrated better tumor coverage with IMRT compared to 3D-CRT, notably due to its ability to more precisely conform to the shape of target volumes while respecting organs at risk constraints. [7-10]. It should also be noted that this advantage of IMRT/VMAT is more pronounced at higher prescription doses [11]. Regarding the conformity index, our study did not show a significant difference between the two techniques, probably due to the small sample size. Generally, in the literature, IMRT/VMAT is associated with a better conformity index due to its angular modulation and its ability to sculpt isodoses around the tumor [7,8,12,13]. Furthermore, a separate study highlighted that plans with lower mean doses, lower maximum doses, and higher minimum doses provide better overall dose uniformity, confirming the value of modulated techniques for dosimetric optimization [14]. Finally, it should be noted that the PTV V107% is an indirect indicator of homogeneity, reflecting the proportion of the volume receiving more than 107% of the prescribed dose. This explains the parallel variation of these two parameters observed in our study.

Regarding the organs at risk, the VMAT technique allows a significant reduction in the maximum dose to the spinal cord (40.85 Gy versus 47.40 Gy) and in the mean doses to the parotid glands (28 Gy versus 38 Gy), thereby providing better protection of healthy structures. These results are consistent with the literature, which reports a significant reduction in spinal cord doses with IMRT compared to 3D-CRT, with decreases of up to 70.3% [11,15].

Several studies have also confirmed the superiority of IMRT in preserving critical structures without compromising tumor coverage, particularly in anatomically complex regions such as the head and neck area [8-10,12,14,16]. It has also been observed in the literature that while the mean fraction doses to the parotid glands vary little across plans, the equivalent doses in 2 Gy fractions (EQD2) differ significantly: 35–42 Gy for IMRT versus 47–48 Gy for 3D-CRT. A comparative study of 3D-CRT versus IMRT in the treatment of head and neck carcinomas further demonstrated that IMRT more effectively spared the parotid glands, with a significant reduction in salivary toxicity [11,16]. Our study shows the same trend, with better protection of critical OARs (spinal cord, brainstem, and parotid glands). Parotid sparing is the most important parameter in terms of reducing both acute and late toxicity related to salivary function.

However, this study is limited by its small sample size, its retrospective nature, and the use of plans from different centers. It should also be emphasized that the quality of IMRT strongly depends on the center's expertise as well as the accuracy of initial contouring and repositioning (flawless IGRT). Nevertheless, it represents one of the few dosimetric comparative studies of 3D-CRT versus VMAT for hypopharyngeal cancer in Africa.

Conclusion

VMAT provides fine dose modulation and better protection of critical organs compared to 3D-CRT, while maintaining equivalent tumor coverage. In resource-limited settings where access to VMAT remains restricted, 3D-CRT remains a valid option, albeit with less effective sparing of organs at risk.

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