Original Article

A Dosimetric Comparison of Volumetric-modulated Arc Therapy and IMRT for Cochlea-sparing Radiation Therapy in Locally Advanced Nasopharyngeal Cancer

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Abstract

Background: Head-and-neck cancer treatment includes radiotherapy as a crucial component. However, radiotherapy, like other treatment modalities, has its own side effects, some of which can be avoided using the latest medical technology and understanding the illness. Despite being a relatively uncommon subtype of head-and-neck cancer, radiation is essential in the treatment of nasopharyngeal carcinoma (NPC). Because of the complex anatomy of the nasopharyngeal region, it is difficult to plan radiotherapy without sparing the cochlea, an important part of the auditory system, and the radiotherapy dosage to it may cause sensorineural hearing loss. In the modern era, volumetric-modulated arc therapy (VMAT) and intensity-modulated radiotherapy (IMRT) have become the gold standard in radiotherapy. With the advancement of these techniques, cochlear sparing is now possible without compromising the tumor dose. **Materials and Methods:** We reviewed 14 plans for patients with locally advanced NPC who had received radiation in our department. VMAT plans were created for patients who had IMRT radiotherapy and vice versa. Both approaches were evaluated in terms of cochlea sparing while maintaining the coverage of the planned target volume (PTV). **Results:** Our study compared the results of two different radiation techniques for locally advanced NPC, IMRT, and VMAT in 14 cases, and we found that VMAT was associated with a lower maximum dose to the cochlea, a lower mean dose to the cochlea, a higher PTV D98% (Gy), a lower PTV D2% (Gy), a higher PTV V95% (%), a lower heterogeneity index, and a higher conformity index. The *P* value for each comparison was <0.05, which indicates that the difference is statistically significant. These results suggest that VMAT is a better radiation technique than IMRT for locally advanced NPC. VMAT is associated with a lower dose to the cochlea and other organs at risk, which can improve the quality of life and survival of patients. **Conclusion:** These results suggest that VMAT is a better radiation technique than IMRT for locally advanced NPC. VMAT is associated with a lower dose to the cochlea and other organs at risk, which can improve the quality of life and survival of patients.

Keywords: Cochlea, intensity-modulated radiotherapy, nasopharyngeal cancer, radiotherapy, volumetric-modulated arc therapy

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Introduction

Nasopharyngeal carcinoma (NPC) is an uncommon cancer worldwide, although it is frequent in South East Asia, with an incidence of 6.4/100,000 males and 2.4/100,000 females.[1] Intensity Modulated Radiotherapy (IMRT) and volumetric-modulated arc therapy (VMAT) are two modern techniques for delivering precise radiation doses to tumors while minimizing exposure to surrounding healthy tissues. Both techniques use computer algorithms to control the intensity and shape of radiation beams, allowing for more precise targeting of tumors.

IMRT delivers radiation from multiple fixed beams that are shaped using a multileaf collimator, which can adjust the shape of the radiation field in real time to conform to the shape of the tumor. In contrast, VMAT delivers radiation from a rotating gantry that delivers the radiation in an arc, while simultaneously varying the beam intensity and shape, providing more efficient and faster delivery of the radiation dose.

The cochlear dosimetric analysis is important in NPC radiotherapy planning to minimize the risk of hearing loss as a side effect. Due to the cochlea's modest volume, traditional dose–volume analyses of the organ were not frequently

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carried out. However, with the advancements in technology, the accuracy of the dosimetric analysis of the cochlea has improved.

Recent studies have shown that both IMRT and VMAT are effective in sparing the cochlea during radiotherapy for locally advanced NPC. However, several studies have suggested that VMAT may have advantages over IMRT in cochlear sparing, with more precise targeting and better dose conformity.

The study included patients with advanced-stage NPC with large, irregular primary tumor bulk (T3 and T4), where it is most difficult to spare the cochlea without compromising the target volume (PTV). Earlier studies, whether dosimetric or clinical, included patients regardless of staging, which could be an important biasing factor in generalizing the results of those studies for every NPC patient.

In our study, we found that VMAT generally produced better treatment plans than 7-field IMRT, when both modalities were optimized to the best of our ability. However, it is intuitive that increasing the number of beam directions would lead to increased intensity modulation and therefore improved IMRT plan quality. Bortfeld mathematically explored this general question and found that the maximum number of beams required for IMRT is proportional to the radius of tumor. He claimed that using more beams beyond this limit would not improve plan quality. However, his derivations were based on a strongly simplified model, and the result was therefore approximate.

While comparing two different radiotherapy techniques, there will always be limitations and scope for improvement of plans. However, clinically, we always try to deliver the best possible plan for the tumor volume, with our primary interest being the coverage of tumor volume and the most critical organs at risk.

Materials and Methods

We observed 14 radiotherapy plans of locally advanced Stage III and IV NPC treated in our hospital between January 2020 and December 2022. All patients underwent simulation using the GE Optima 580W® dedicated CT simulator (Wipro GE Healthcare, Chicago, USA) and received treatment on Elekta Versa HD linear accelerator (Elekta Oncology Systems, Crawley, UK) machine. Eight patients have received radiotherapy by VMAT technique while six patients received radiotherapy by IMRT. Contouring was done as per international consensus guidelines.[2] Plan optimization was done on the Monaco (V 5.51.10) treatment planning system.

All patients received a total radiotherapy dose of 70 Gy in 35 fractions over a period of 7 weeks. For patients who had previously been planned by IMRT, a new VMAT plan with 6 MV energy and a dose rate of 600 MU/min (monitoring units per minute) was developed with two coplanar complete arcs (clockwise and counterclockwise) using a collimator angle of 30° and 330°, respectively. The planning was done on a 0.25 cm slice thickness computed tomography (CT).

For patients who had previously been planned by VMAT, a new IMRT plan was created using 6 MV energy and an average dose rate of 300 MU/min with equally spaced 7-field step and shoot IMRT and 51° spacing between each beam. The collimator angle for all beams was 0°. Planning was done on a 0.25 cm slice thickness CT.

Several planning variables, such as mean cochlear dose, PTV coverage, D_{mean}, D_{max}, D98%, V95%, D2%, and dose to other organs at risk (OARs) were compared to the primary plans.

Paired *t*-test was used to evaluate differences in the cochlea sparing where a P value below 0.05 was considered significant. All plans were in accordance with the International Commission on Radiation Units 83 report.

Results

Fourteen plans of patients with locally advanced Stage III and IV NPC were evaluated for cochlear dose and PTV coverage. The average age of the patients was 46 years.

In our study, 85% of the patients had Stage IV disease and 72% of the patients overall were male [Table 1].

The mean cochlear volume of our plans was 1.15 ml. The D_{max} and D_{mean} value of both the cochleae was significantly better in VMAT plans [Table 2]. With respect to PTV D98%, PTV D2%, and PTV V95%, VMAT plan was significantly better than the IMRT plan [Table 2].

The mean PTV volume was 799.4 cc, and except for one patient included in our study, all 13 other patients were having disease volume above 750 cc [Figure 1].

As compared to IMRT, VMAT was associated with a lower maximum dose ($P < 0.001$), mean dose ($P < 0.05$), PTV D98% (Gy) ($P < 0.05$) and heterogeneity index (HI) ($P = 0.008$). VMAT was associated with a higher PTV D2% (Gy) ($P < 0.05$), PTV V95% (%) ($P < 0.05$) and a comparable conformity index (CI). These results suggest that VMAT is a better radiation technique than Intensity Modulated Radiotherapy (IMRT) for locally advanced NPC.

The results of this study suggest that VMAT may be a better option than IMRT for patients with locally advanced NPC.

Table 1: Characteristics of patients studied

Characteristics	Frequency
Age (years)	
30–40	2
40–50	8
50–60	4
Sex	
Male	12
Female	2
Tumor size	
T3	4
T4	10

Table 2: Comparison of dosimetric values of intensity-modulated radiotherapy and volumetric-modulated arc therapy plans

	IMRT	VMAT	*P*
D_{max} (rt)	48.18±10.11	40±5.05	0.012
D_{max} (lt)	50.84±5.7	46.21±5.08	0.032
D_{mean} (rt)	43.16±6.7	38.26±5.32	0.041
D_{mean} (lt)	42.13±5.46	38.05±4.69	0.043
PTV D_{mean}	69.59±0.3	69.69±0.64	0.6
PTV D98% (Gy)	66.65±0.34	67.03±0.46	0.019
PTV D2% (Gy)	71.96±0.34	71.45±0.68	0.018
PTV V95% (%)	98.16±0.33	98.71±0.62	0.007
HI	1.11±0.08	1.05±0.03	0.008
CI	0.85±0.22	0.85±0.05	1

IMRT: Intensity Modulated Radiotherapy, VMAT: Volumetric-modulated arc therapy, PTV: Planning target volume, HI: Heterogeneity index, CI: Conformity index

VMAT is associated with a lower dose to the cochlea and other organs at risk, which can improve the quality of life and survival of patients.

Discussion

NPC is a common head-and-neck malignancy, and without radiotherapy, its treatment is incomplete.[3] With advancements in radiotherapy techniques, patient response and toxicity profiles have changed significantly, improving patient survival. Previously, it was difficult to spare OARs without compromising the primary tumor dose, which causes a lot of toxicity and leads to incomplete treatment or poor patient quality of life.

In our study, we dosimetrically compared two advanced radiotherapy techniques, IMRT and VMAT, in terms of cochlear dosage with the least acceptable compromise in PTV coverage. This comparison provides an overview of which technique is best suited for treating locally advanced NPC.

Hearing loss is one of the most common late effects of radiotherapy in NPC. This event can be caused by a variety of factors, including the dose to the auditory apparatus, chemotherapy, and the patient's age at the time of treatment. Because the cochlea is the most radiotherapy-sensitive part of the auditory apparatus, it is critical to spare it as much as possible in order to reduce the incidence of hearing impairment in patients with NPC who have received radiotherapy. Many dose constraints for radiotherapy to the cochlea have been proposed in recent years. According to the Quantitative Analysis of Normal Tissue Effects in the Clinic (QUANTEC) guidelines, the incidence of sensorineural hearing loss (SNHL) in patients receiving a mean cochlear dose of ≤45 Gy is approximately 30% in the three-dimensional technique.[4] With the development of advanced techniques such as IMRT and VMAT, these techniques have become the standard of care, and it is now possible to reduce the radiotherapy dose to the cochlea as much as possible while still covering the primary tumor.

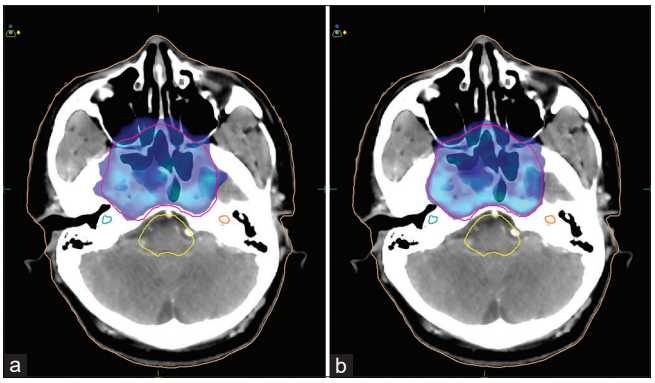

Figure 1: Dose distribution on axial computed tomography image: (a) IMRT plan, (b) Volumetric-modulated arc therapy plan. IMRT: Intensity modulated radiotherapy

SNHL was detected in 91 of the 170 ears (54%) studied in a study conducted by Chan *et al*. There was an increased risk of SNHL for ears receiving D_{mean} >47 Gy compared to those receiving dose ≤47 Gy at all frequencies within the range of speech.[5]

In a study conducted by Lee *et al*., two common normal tissue complication probability models, the logistic and the Lyman–Kutcher–Burman models, were used to quantify the relationship between the incidence of tinnitus toxicity and the dose–response effects in the cochlea with the aim of identifying a specific dose relationship; a dose of <32 Gy to the cochlea was suggested to maintain the incidence of Grade 2+ tinnitus toxicity <20% in IMRT. Achieving a mean dose of <32 Gy was very much possible in the study by Lee *et al*. as it included cancer patients of head and neck region irrespective of subsite and stage.[6] Where as our study population was of stage III and IV NPC, which might have led to compromise of PTV.

According to a study by Pelliccia *et al*., the mean cochlear volume is 0.06–1.12 ml. In our study, the mean cochlear volume is 1.15 ml which is toward the maximum range, and hence, the dose received by cochlea will be more as compared to patients having less cochlear volume.[7]

Furthermore, the cochlear dose will also depend on the volume of PTV, as in larger volumes, cochlear sparing will cause a significant compromise at PTV.

In a study conducted by Braun *et al*., IMRT achieved a unilateral mean cochlear dose of <10 Gy at the spared site while the nonspared site achieved a mean cochlear dose ranging from 18.7 to 30.3 Gy. The mean cochlear doses achieved in our dosimetric analysis were 38 Gy and 42 Gy in VMAT and IMRT plans respectively. We only included patients with NPC, whereas none of the patients in Braun *et al*.'s study had NPC, so our mean cochlear dose was higher than that of Braun *et al*.'s study, but it was within the range of QUANTEC recommendations.[8]

In a study conducted by Gao *et al*., VMAT was compared to IMRT in terms of cochlear sparing which suggested a better outcome with VMAT in terms of both mean radiotherapy

dose to both spared or nonspared cochlea and planning target volume (PTV) coverage.[9] Our study concluded the same results and shows that cochlear sparing is better in VMAT plans as compared to IMRT plans.

The re-optimized plans in another trial by Lamaj *et al*. produced a median dose for left and right of 14.97 Gy and 18.47 Gy versus 24.09 Gy and 26.05 Gy, respectively, with $P = 0.001$ when compared to the reference plans. Since patients with only Stage III and Stage IV NPC were included in our investigation, the mean dose achieved in comparison to this study was 38 Gy, whereas only 40% of patients with the same stage were included in Lamaj *et al*.'s study.[10]

In our study, the mean volume of PTV is 799.4 cc which is higher as compared to most of the other studies where a comparison of VMAT has been done with IMRT for OAR preservation without any significant change in PTV coverage.

Cochlea-sparing radiotherapy can lead to complications such as missed target volumes or poor-quality treatment plans. To minimize these risks, it is important to use the most appropriate technique available. In a study conducted by Vanetti *et al*., plans generated by VMAT were superior to IMRT plans in terms of HI and CI.[11] The plans generated in our study using IMRT and VMAT techniques had differences that were significant. Specifically, the VMAT plan had a significantly better HI compared to the IMRT plan. These results suggest that the use of VMAT may help to minimize the dose to cochlea without any compromise in PTV coverage.

Our study has several limitations. New VMAT techniques have emerged in the past few decades, which allow for multiple arcs and noncoplanar arrangements. However, these solutions were not the focus of our investigation and require further comparisons. Future studies should examine the role of noncoplanar techniques and the number of modulated arcs needed to achieve the ideal dose distribution. In our study, we have compared IMRT to VMAT with two arcs only. Furthermore, we included only 14 NPC radiation plans, which is a small sample size; therefore, additional dosimetric analysis with a larger sample size will be required to strongly infer the advantages of VMAT. Second, a longer clinical follow-up of patients will also help to clinically evaluate the cochlear toxicity which patients may have received from radiotherapy.

Conclusion

Our study suggests that VMAT is a better radiation technique than IMRT for locally advanced NPC. VMAT can reduce the dose to the cochlea during radiation, without the use of any other cochlea-sparing techniques. This can improve the quality of life and survival of patients. Additional techniques, such as adding a planning organ at risk volume margin over OARs and reoptimizing plans, can further spare the OARs.

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Conflicts of interest

There are no conflicts of interest.

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