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Study the Quality of IMRT and VMAT Treatment Planning Techniques (TPS) Using Indices of Achievement (IOA) Nasopharyngeal Cancer Plans

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Abstract

Volumetric Modulated Arc Therapy (VMAT) and Intensity Modulated Radiation Therapy (IMRT) are comparable for nasopharyngeal cancerous radiation therapy. This research intends to analyze the high-quality plan using accomplishment, conformance, and homogeneity criteria.

The study involved 40 patients with a postnasal cancerous tumor. The patients underwent computed tomography (CT) simulation to scan the anatomical details of the patients' heads. Then, their data was forwarded to the treatment planning system (TPS) workstation for IMRT and VMAT planning. The plans were evaluated using the IOA, HI, and CI indices.

The nasopharynx coverage results consist of the GTV and PTV at 95%. The statistical study reveals that VMAT provides much more coverage than IMRT for 95% GTV and 95% PTV. The results reveal that VMAT has a substantially better-quality plan (IOA) than IMRT. IMRT provides a superior CI, but VMAT protects the cochlea and optic nerves more effectively. In addition, the IMRT is advantageous for the preservation of additional OARs. There is no statistical difference in protection for the mandible and parotid glands between the two procedures. The VMAT has superior coverage for the gross and planned target volumes and achievement indices. The conformity of IMRT in the tumor target area is better, while VMAT can better protect the cochlea and optic nerves.

Keywords: IMRT, VMAT, Index of Achievements, Nasopharyngeal, Gross Target Volume

1. Introduction

Radiation treatment for cancer aims to eradicate tumors while sparing surrounding healthy tissue [1]. Radiation interaction in the matter is more obvious than resolved since it results in a non-specific change phase that does not distinguish between malignant and ordinary tissues. Tumors and normal tissues are susceptible to biological harm induction [2, 3]. It follows that the maximum dosage that may be delivered to the tumor is limited by the tolerance of the normal tissue in the treatment area. Several strategies have been proposed to overcome this therapy bottleneck and provide more effective care for tumors [4, 5].

The treatment planning term describes the whole technical process, from patient data acquisition to treatment verification. There are many techniques to deliver the radiation dose to the tumor[6, 7].

Intensity-Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) are modern planning approaches that combine linear accelerators to safely deliver precision radiation to a tumor while limiting the exposure to surrounding normal tissue. To improve the composite dose distribution, a non-uniform fluence of radiation is provided to the patient from any given point of the therapy beam [8, 9].

Nasopharyngeal cancer (NPC) is difficult to treat with radiation treatment (RT). More than a third of patients with locally advanced illnesses treated with two-dimensional treatment planning(2DRT) alone still experience local recurrence, even though distant dissemination is the most prevalent failure location [10, 11]. Patients with locally advanced NPC who get radiation in combination with chemotherapy have a local control rate of around 95%. Furthermore, the nasopharynx is bordered by important neurological tissues and sensitive structures, including the ear, jaw, temporomandibular (TM) joints, and parotid glands, the health of which is critical to the patient's well-being [12, 13].

Some studies have demonstrated local control rates for cancers above 80% after three years [14, 15]. As a result of three-dimensional conformal radiotherapy, with three-dimensional treatment planning (3D-CRT) and precise estimates of tissue heterogeneities, it is now feasible to precisely define target volumes and organs at risk (OARs). However, three-dimensional treatment planning (3D-CRT) has not optimized dose uniformity and conformity to NPC's concave and sometimes irregularly shaped target volumes. Traditional methods for assessing the efficacy of RT regimens have relied on biologically relevant models like the tumor control probability (TCP) and the normal tissue complication probability (NTCP). Several studies have focused on developing TCP models for an inhomogeneously irradiated tumor [16, 17]. In order to define "achievement" in dosage painting (DP) programs, Park et al. compared planned and prescription physical dose distributions. They wanted a new homogeneity indicator that took biological impact into account; therefore, they came up with the IOA. In addition, the uncertainty problem means that there is no guarantee that IOA correlates with the biological effect [18, 19].

Intensity-modulated radiation therapy with photons (IMRT) or volumetric modulated arc therapy (VMAT) or so-called VMAT has been used clinically in recent years for non-small-cell lung cancer (NSC) patients whose tumor-free survival rates have increased and who have experienced fewer RT-related side effects, such as Xerostomia, thanks to the technique's dosimetric advantages [20, 21].

Recently, volumetric modulated arc treatment (VMAT) was created as an arc therapy to address shortcomings in the IMRT method. The idea of VMAT is that the patient may be continually treated from any angle, up to a full 360 degrees, thanks to the source's ability to always rotate. Rapid arc's key benefit over conventional IMRT is the reduced treatment time. Compared to other IMRT delivery methods, VMAT may lower both the monitor unit and the total dose. This can help lower the risk of some side effects or the development of a second cancer (the sliding window approach and those not based on direct aperture optimization [22, 23]).

While VMAT (or IMRT) is the current gold standard, a 2016 ESTRO study of centers in 24 European nations found that over 30 percent of those surveyed reported using 3-dimensional conformal radiation (3DCRT) on the head and neck [24, 25]. This demonstrates the ongoing need to improve radiotherapy's efficacy while minimizing its negative side effects, even in

industrialized nations. In 2014, Park et al. first proposed indexes of achievement (IOA). The discrepancy between the recommended dosage and the intended dose is calculated as the volume-weighted average. The formula for this index is as follows [26]:

$$IOA = 1 + \sqrt{\sum_i \left[\left(\frac{D_{i,plan} - D_{i,Rx}}{D_{i,Rx}} \right)^2 \times \frac{v_i}{V} \right]}$$

$D_{i,plan}$, $D_{i,Rx}$, Plan represent the prescription and planned dosage for the voxel, whereas V represents the entire volume of the target. If the value is 1, then the prescription and intended doses are the same; if it's not, the difference is more than 1.

The conformity index (CI) and the homogeneity index (HI), which are usually used in clinical practice to review plans, need to be changed for DP planning because they were created with the idea of uniform dosage prescription in mind. The anticipated dosage distribution within a target volume may be evaluated using the homogeneity index (HI) (or uniformity index). Although it does not provide as much information as the dose-volume histogram (DVH), the ease with which it may be generated makes it a promising tool for assessing whether a tumor volume has been treated with a uniform dosage. Various formulas for indexing different types of literature have been developed. The gradient index (GI) has been devised to quantify dosage gradients [27, 28] easily.

The GI is calculated by dividing the volume of half the prescription isodose by the volume of the prescription isodose. R50 percent, the 50% prescription isodose volume ratio of the planned target volume (PTV), has been extensively used to evaluate the dose gradient beyond the PTV into normal tissue structures. [29,30]

This study aims to investigate the plan with high quality using indices of achievement, conformity, and homogeneity.

2. Materials and Methods

This is a retrospective study conducted at Al-Warith Cancer Institute from January 2022 to June 2022. Forty patients with postnasal cancerous tumors were included in this study. An oncologist made the diagnosis for each of these patients, and they were all then given chemotherapy and radiotherapy. The patients underwent a computed tomography (CT) simulation of 64 multi-slice CT scanners deliver optimal image quality, manufactured by Siemens in the USA, for scanning the anatomical details of the patient's head. Then, the patient's data is forwarded to the treatment planning system (TPS) workstation. The radiation oncologist delineates the gross target volume (GTV), the planning target volume (PTV), and the organs at risk, such as the left and right cochlea. Right lenses, mandible, left and right optic nerve, and left and right parotid glands. The medical physicist generates two plans: IMRT and VMAT in Eclipse TPS, Varian, and USA. The plans were evaluated using the IOA, HI, and CI indices. The statistical analysis was performed in SPSS 25 at a p-value equal to or less than 0.05. The recommended measured dose of the OAR is shown in **Table 1** [31]:

Table 1. The recommended measured dose of the OAR

Volume	Dose (Gy)
Cochlea-Left	$D_{max} \leq 25$ Gy
Cochlea-Right	$D_{max} \leq 25$ Gy
Eye-L	$D_{max} \leq 25$ Gy
Eye-R	$D_{max} \leq 25$ Gy
Larynx	$D_{mean} < 30$ Gy
Lens-L	$D_{max} \leq 25$ Gy
Lens-R	$D_{max} \leq 25$ Gy
Mandible	$D_{max} \leq 65$ Gy
Optic Nerve-Left	$D_{max} \leq 54$ Gy
Optic Nerve-Right	$D_{max} \leq 54$ Gy
Parotid Gland-Left	$D_{mean} < 26$ Gy
Parotid Gland-Right	$D_{mean} < 26$ Gy

3. Results

The results of the coverage for the nasopharyngeal are presented in **Table 2.** The results included the GTV and PTV at 95% of the isodose line. The statistical analysis shows that the coverage in the VMAT technique was significantly higher than the IMRT for both GTV 95% and PTV 95%, as presented in **Figures 1 and 2**.

Table 2 The results of the coverage for the nasopharyngeal

Target	IMRT	VMAT	p-value
GTV 95%	94.60 ± 13.50	96.30 ±16.12	0.03622*
PTV 95%	95.01 ± 14.64	97.49 ± 15.18	0.02619*

***Significant Difference at *p*-value ≤0.05002**

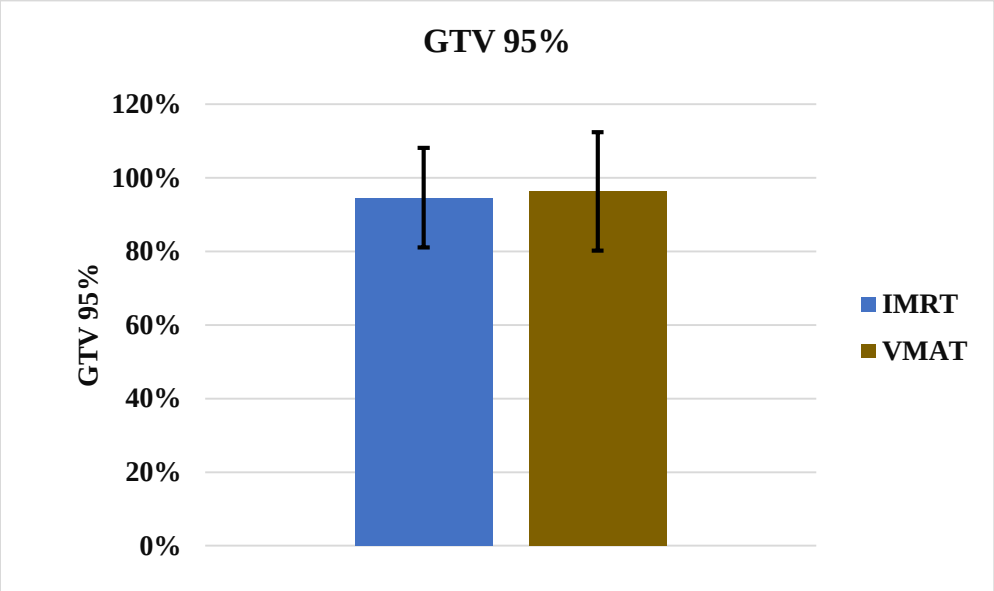

Figure 1. Comparison between the IMRT and VMAT for the Gross Target Volume at isodose 95% (GTV**).**

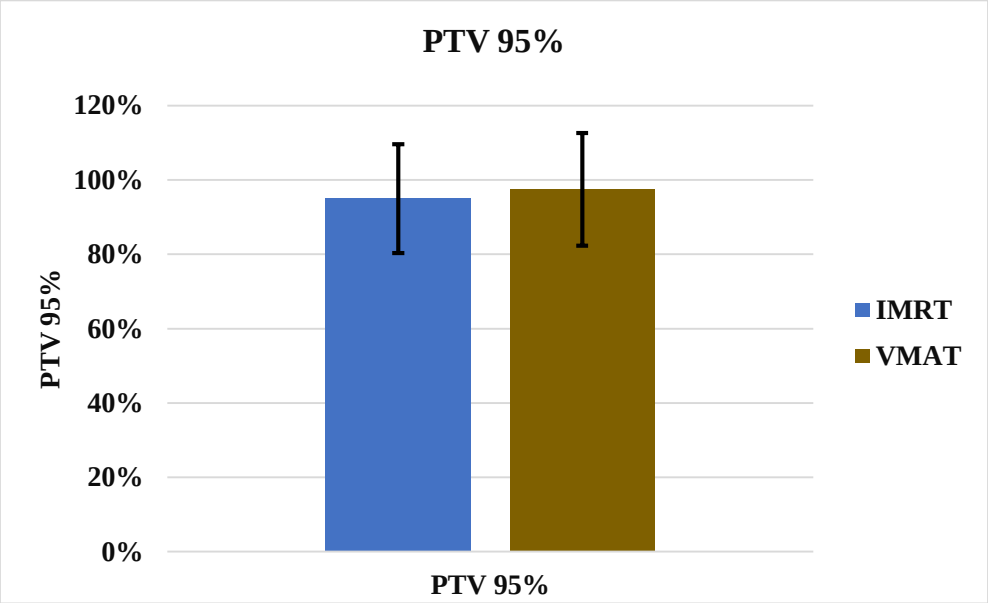

Figure 2. Comparison between the IMRT and VMAT for the Planning Target Volume at isodose 95% (PTV).

The plan quality in this study was calculated by the four indices, IOA, HI, CI, and GI, as shown in **Table (3).** The IOA is the main evaluation index in this study. The results show that the VMAT shows a significantly better plan (IOA) quality than the IMRT, as shown in **Figure (3),** while the IMRT shows better conformity indices (CI) than the rapid arc, as shown in **Figure (4).** The homogeneity (HI) and gradient (GI) indices were not significantly different between the two treatment planning techniques, as presented in **Figure (4).**

Table 3. The plan quality of the four indices, IOA, HI, CI, and GI

Indices	IMRT	VMAT	p-value
IOA	1.19 ± 0.06	1.07 ± 0.02	0.0293*
CI	1.05 ± 0.07	1.21 ± 0.04	0.0157*
HI	0.51 ± 0.06	0.52 ± 0.03	0.06612
GI	4.98 ± 1.01	3.15 ± 0.98	0.0528

*** Significant Difference at *p*-value ≤0.05.**

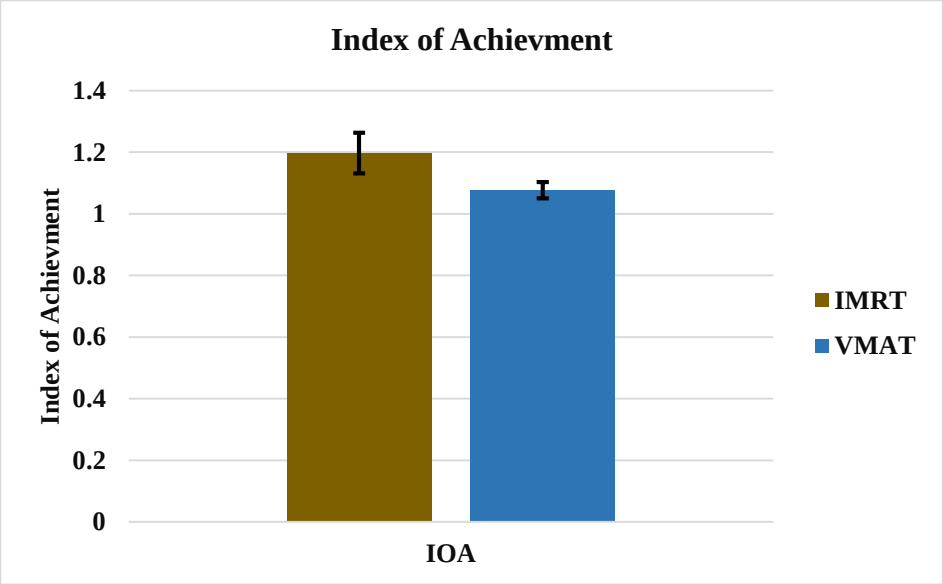

Figure 3. Comparison between the IMRT and VMAT for Indices of Achievement (IOA).

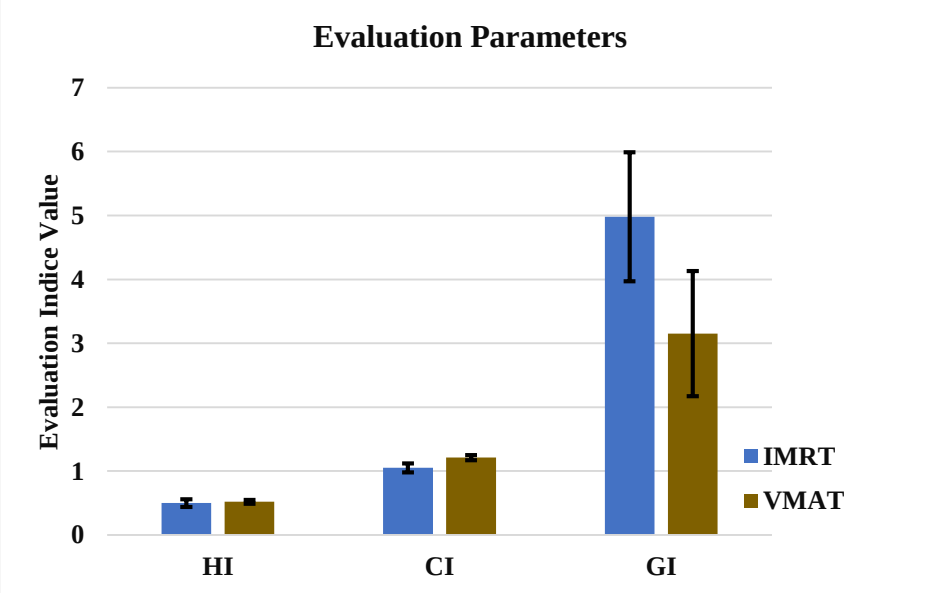

Figure 4. Comparison between the IMRT and VMAT for Homogeneity (HI), Conformity (CI), and Gradient (GI) Indices.

Table (4) illustrates the maximum and mean doses for at-risk organs. The organs at risk (OARs) involved in this study were the left and right cochlea, left and right lenses, mandible, left and right optic nerve, and finally, left and right parotid glands. The analysis shows that the VMAT had a significantly lower dose than IMRT in the left and right cochlea, left lens, and Optic Nerve-Left doses. No significant difference in dose reached the larynx, right lens, mandible, or right optic nerve between the IMRT and VMAT. The VMAT shows that it protects the left lens more significantly than the IMRT. At the same time, the IMRT provides significantly better protection for the left optic nerve and left lenses.

Table 4. The maximum and mean doses for at-risk organs

Volume(Gy)	IMRT	VMAT	p-value
Cochlea-Left			
$\mathbf{D_{max}}$	20.91 ± 4.75	18.33 ± 5.32	0.0362*
Cochlea-Right			
$\mathbf{D_{max}}$	22.04 ± 3.05	19.28 ± 2.05	0.0495*
Larynx			
$\mathbf{D_{mean}}$	20.34 ± 9.03	21.66 ± 8.33	0.0926
Lens-L			
$\mathbf{D_{max}}$	20.64 ± 1.76	23.09 ± 2.07	0.0019*
Lens-R			
$\mathbf{D_{max}}$	21.32 ± 3.12	22.96 ± 5.54	0.2951
Mandible			
$\mathbf{D_{mean}}$	42.85 ± 20.53	36.39 ± 18.17	0.4842
Optic Nerve-Left			
$\mathbf{D_{max}}$	40.01 ± 13.02	47.2 ± 10.77	0.0003*
Optic Nerve-Right			
$\mathbf{D_{max}}$	40.02 ± 6.06	42.04 ± 8.07	0.0680
Parotid Gland-Left			
$\mathbf{D_{mean}}$	12.08 ± 4.97	12.97 ± 2.67	0.0764
Parotid Gland-Right			
$\mathbf{D_{mean}}$	13.76 ± 5.97	15.98 ± 2.94	0.0597

*** Significant Difference at *p*-value ≤0.05.**

4. Discussion

The recommended and most successful treatment for nasopharyngeal cancer is radiotherapy. Significant therapeutic improvements have resulted from the radiation industry's ongoing technological advancements [32]. The coverage findings for the nasopharynx are comprised of the GTV and PTV at 95% of the isodose line. The statistical analysis demonstrates that the VMAT

method provided considerably more coverage than IMRT for both GTV 95 percent and PTV 95 per cent.[33]

The VMAT method has recently gained widespread popularity, with less time spent in therapy. In treating head and neck malignancies and certain somatic tumors, it has been shown that VMAT offers dose distributions equivalent to or better than IMRT. These results agreed with the study of Chen et al., who found that the VMAT shows a better dose distribution to the target volume. Chen et al. disagree with our findings about the GTV; when they compared the GTVs of the two groups, they found no significant difference, ruling out the possibility that the size of the original tumor mass had a role in the degree to which it shrank. They concluded that the finding proved that the two methods achieved similar results [34, 35].

This research determined the plan's quality by the four indices IOA, HI, CI, and GI. The IOA is the primary assessment indicator in this study. The findings indicate that VMAT has a much higher plan (IOA) quality than IMRT. [36]

As demonstrated in the study, the IMRT has a higher conformity index (CI) than the fast arc. This study also shows that the homogeneity (HI) and gradient (GI) indices did not vary substantially between the two treatment planning techniques. [37]

The target volumes, the delivery system, and the radiation technology define the uniformity and homogeneity of the dose distribution inside the PTV. Evidence from much research suggests that a single-arc VMAT strategy may not be preferable to a fixed-beam IMRT approach [38].

Zhang et al. demonstrated that the VMAT designs produced PTVs with higher CIs than the IMRT plan. However, save for the c-IMRT plan having a higher HI than the 1A VMAT plan, there was no discernible difference between them. Additional research showed that the 2A and 3A designs increased the PTV's CI and HI by 0.088 and 0.089, respectively, compared to the 1A plan (0.85 and 1.08, respectively). On the other hand, the 2A and 3A plans did not vary much from one another. [39]

However, neither homogeneity nor agreement between the methods for the locally progressed disease was seen. Since radical radiation was needed for treatment right away, a compromise had to be made because the tumor was big and close to important organs in the area where the disease was already very advanced. For example, the mean dose to the parotid gland is an OAR, for which a VMAT plan may serve as a useful restriction. Johnston et al.'s research also showed that VMAT offered superior parotid gland protection. The research, as mentioned earlier, used two distinct radiation delivery methods—double-arc VMAT and step-and-shoot IMRT—which may account for the contradictory findings. This finding is consistent with previous reports by Vanetti et al. and Ning et al. comparing the amount of healthy tissue outside the treatment region exposed by each VMAT and IMRT method. For low doses (V5-V35), we discovered that VMAT reduced the exposure volume of healthy tissue, notably at V20 and V25.
The maximum and mean dosages for the organ at risk were included in this study. The left and right cochlea, left and right lenses, mandible, left and right optic nerve, and left and right parotid glands were the OARs examined in this research. The study reveals that the fast arc delivered a much lower dosage to the left and right cochleae and left lens than IMRT. There is no substantial

difference between IMRT and VMAT in the dosage delivered to the larynx, right lens, mandible, and right optic nerve. The fast arc protects the left lens much more than IMRT. While IMRT significantly improves the preservation of the left optic nerve and left lenses, [40]

Chen et al. particularly disagreed with the findings of this study when they reported that the IMRT's clinical use yielded positive outcomes that enhanced not only local control and long-term survival rates for NPC but also the quality of life of the patients.

In prior research, researchers compared VMAT with IMRT using two sets of plans created for the same patient's target region. However, only one treatment strategy may be used in a patient's real case. For this reason, the clinical condition may be more accurately reflected by randomly assigning matched patients to either the VMAT plan or the IMRT plan in the prospective manner used in this research. After a careful and systematic allocation, the gross tumor volumes of the two matched groups did not vary significantly from one another. Consistent with Vanetti et al. and Johnston et al., the clinical requirements of recommended dosage coverage of the PTVs were satisfied by both the VMAT and IMRT programs.

In this approach, VMAT may provide superior tumor management and enhanced efficiency, resulting in enhanced patient comfort and positional stability. Additionally, more patients may be treated if the time it takes for each exposure is shortened. Because of this, VMAT radiation equipment may be utilized more effectively, allowing more patients to get timely treatment. Increased access to high-quality radiation is possible through VMAT because of its shorter treatment times [41].

5. Conclusion

We concluded that the VMAT had superior coverage for the gross and planning target volumes. The achievement indices were a good indicator for target volume dose distribution, especially when the VMAT showed a better IOA. The homogeneity and gradient index show no significant difference between the two techniques. The conformity of IMRT in the tumor target area is better, while VMAT can better protect the cochlea and optic nerves. Furthermore, the IMRT shows a benefit in the protection of other OARs. Mandible and parotid glands have no statistically different protection between the two techniques. to find the proper technique for treating the nasopharyngeal tumor.

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Conflict of Interest

The authors declare that they have no conflicts of interest

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