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LETTER TO THE EDITOR

Novel VMAT planning technique improves dosimetry for head and neck cancer patients undergoing definitive chemoradiotherapy

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Background

Cancers of the head and neck are relatively rare, with cancers of the lip, oral cavity, pharynx, and larynx estimated to represent fewer than 5% of all malignancies diagnosed in Europe in 2020 [1]. Furthermore, these cancers can demonstrate vastly divergent prognoses based on the primary site of disease, stage at diagnosis, and tumor biology [2]. In particular, there has been a dramatic epidemiologic shift in oropharyngeal cancers of the lingual and palatine tonsils with an ongoing surge in human papillomavirus (HPV) associated squamous cell cancers and a concomitant decrease in smoking-related cancers of the same pharyngeal surfaces [3]. Many of these cancers, particularly those that are locally advanced, are treated non-operatively with concomitant chemotherapy and radiotherapy. While these treatments are often associated with excellent oncologic outcomes, particularly in the HPV-positive population, the acute and late toxicity of head and neck radiotherapy can be notably severe [4].

Massive technical improvements over the past three to four decades have allowed for more precise delivery of therapeutic radiation to this sensitive area of the body. Intensity-modulated radiotherapy (IMRT) was initially developed in the 1980s, beginning with a seminal report on inverse planning from the Karolinska Institute of Stockholm [5]. Over the course of the following two decades, the technology grew from a niche area of physics experimentation to rapid, widespread clinical adoption around the turn of the millennium [6]. Although IMRT was adopted in many disease sites without substantial clinical evidence, a phase III randomized clinical trial (PARSPORT) confirmed the utility of the technique for patients with head and neck cancers. Compared with 3D conformal radiotherapy (3D-CRT), patients treated with IMRT experienced lower rates of xerostomia, better saliva recovery following treatment, and improved quality of life without detriment to oncologic outcomes [7]. Shortly after the start of the new millennium, a form of rotational IMRT known as volumetric modulated arc therapy (VMAT) became widely available, permitting much faster treatment times while preserving the dosimetric advantages of traditional fixed field IMRT [8,9].

Despite these clear clinical improvements, IMRT or VMAT planning requires substantially more effort and expertise from physicians, dosimetrists, and physicists, particularly given the anatomical complexity of the head and neck region [10]. Furthermore, there is widespread variation in IMRT or VMAT planning across centers, and there are limited published data to guide planning development [11–14]. While some knowledge-based or automated planning systems are in the early stages of development, these are not widely available yet in clinical practice. Furthermore, these systems typically aim to optimize the algorithmic, inverse-planning portions of treatment development but do not aid in the initial selection of arc number or geometry. In this study, we hypothesize that our institutional approach to VMAT planning for head and neck patients can improve dosimetry and reduce overall planning time without the need for costly third-party solutions.

Materials and methods

Ten consecutive patients diagnosed with head and neck cancer who received chemoradiotherapy with definitive intent were included in this single-institution dosimetric planning study. Patients receiving unilateral neck irradiation were excluded from the study. To ensure consistency among patients, all target volumes and organs-at-risk (OARs) were contoured by a single physician (M. C. Repka). VMAT plans were generated per institutional (NYU Langone - Long Island) protocol using 6 MV photon beams. Plans were designed to deliver 54.12–56 Gy to a standard-risk elective

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volume for all patients, 59.4–63 Gy to an intermediate-risk elective volume in select patients, and 69.96−70 Gy to gross disease, all in 33–35 fractions using a simultaneous integrated boost (SIB) technique.

For patients planned with our institutional planning protocol, three full arcs were employed with assigned collimator angles of (C) 0°, (C) 90° and (C) 90°. Isocenter placement was performed by the treating physician per standard institutional practice at the anterior edge of the C2 vertebral body at the midline in order to encompass the inferior and superior extent of the treatment volumes. The maximum jaw extension of the (C) 0° field encompassed the entirety of the treatment volume. The inferior jaw on the first collimated arc was set with a maximum extension of 1 cm beyond the isocenter, while the superior jaw of the second collimated arc was set with a maximum extension of 1 cm beyond the isocenter. Otherwise, jaws were set to encompass the treated volume. Comparison plans were generated for each patient using the manufacturer's recommended beam arrangement, comprising two full collimated arcs - (C) 30° and a reciprocal (C) 330° - with jaw tracking enabled. For both institutional and standard plans, a full 360° rotation was used for each individual arc. Sample beam arrangements for institutional and 'industry standard' plans are shown in the Supplementary Materials, as are institutional dose constraints. All plans were generated using Varian Eclipse (Version 15.6, Varian Medical Systems Inc., Palo Alta, CA) for treatment on a Varian TrueBeam linear accelerator (Varian Medical Systems Inc., Palo Alta, CA). Dose calculation was performed using the Anisotropic Analytical Algorithm (AAA). Initial plan evaluation and DVH analysis were performed using ClearCheck (Radformation Inc., New York, NY).

Mean differences in target volume and OAR dosimetry between planning approaches were calculated. Target volumes included high-risk PTV and low-risk PTV while OARs included brainstem, spinal cord, spinal cord planning organ-at-risk volume (PRV) comprising a 5 mm geometric expansion on the spinal cord, ipsilateral and contralateral parotid glands, mandible, pharyngeal constrictors, cricopharyngeus, ipsilateral and contralateral cochleae, ipsilateral and contralateral brachial plexus, ipsilateral and contralateral optic nerves, optic chiasm, pituitary, oral cavity, and global maximum point dose. Monitor units (MUs) were recorded for all plans. The Wilcoxon signed-rank test was employed to determine statistically significant differences in dosimetry between standard and institutional plans. A p-value < 0.05 was considered statistically significant for the purposes of this analysis. Statistical analysis was performed using Excel (Version 16.67, Microsoft Corp., Redmond, WA) and SPSS (Version, 28.0.0.0, IBM Corp., Armonk, NY).

Results

A total of ten consecutive patients were identified and planned using both standard two-arc (group 1) and institutional (group 2) protocols. All patients had primary mucosal squamous cell carcinomas which originated from the larynx [5], oropharynx [4], and nasopharynx [1]. Nine patients were treated in 35 fractions, while a single patient was treated in 33 fractions. In all patients, a PTV coverage of $V100 \geq 95\%$ was achieved for both standard- and high-risk target volumes. As intermediate-risk target volumes were not employed in all patients, these data were not included in the comparative analysis. The spinal cord $V45Gy < 0.03$ cc was considered a hard constraint and achieved in all twenty plans. Additional constraints are available in the Supplementary Materials. Certain OARS were not contoured for all cases (temporal lobes, optic nerves, optic chiasm, pituitary, and oral cavity) and consequently, these OARS were removed from the analysis. Comparative dosimetry for all patients and plans was available for the spinal cord, spinal cord PRV, brainstem, ipsilateral and contralateral parotid glands, mandible, pharyngeal constrictors, cricopharyngeus, ipsilateral and contralateral cochleae, as well the global maximum point dose.

Statistically, significant mean improvements were observed in ipsilateral parotid mean dose, ipsilateral parotid V30Gy, contralateral parotid mean dose, contralateral parotid V30Gy, total parotid volume receiving less than 20 Gy, pharyngeal constrictor mean dose, cricopharygenus mean dose, ipsilateral cochlea mean dose, contralateral cochlea mean dose, ipsilateral brachial plexus maximum dose, and global maximum dose with the three-arc technique. As expected, significantly more mean MUs were needed for the three-arc plans (862.0 vs. 470.3, $p = 0.005$). No significant differences in PTV, spinal cord, mandible, contralateral cochlear, or contralateral brachial plexus dosimetry were identified. Subjectively, dosimetrists reported shorter planning time and easier achievement of planning objectives with the three-arc approach. Detailed dosimetric information is demonstrated in Table 1. Box-and-whisker plots for planning goals are demonstrated in Figure 1.

Discussion

The institutional approach to head and neck VMAT planning detailed in this report conveys significant dosimetric improvements in multiple OARs compared to a standard VMAT beam arrangement. The major strength of this study is the direct comparison of the planning approaches in the same patients using the same target volumes. Additionally, this approach is easily reproducible and does not require additional investment in equipment or software beyond what is readily available in the majority of radiation oncology centers in the United States. Consequently, there is essentially no barrier to rapid clinical implementation. While tools exist that allow dosimetrists to maximize plan optimization, they require financial investment beyond the standard treatment planning software and do not provide insight into the optimal arrangement or number of arcs [15].

A significant limitation to this study is the lack of available data in regard to treatment planning time. IMRT planning for head and neck cancer is notoriously complex and time-consuming [9,16]. Subjectively, dosimetrists report easier achievement of planning goals in a shorter time and with fewer iterations than with the institutional approach, but this

Table 1. Target and OAR dosimetry with standard (Group 1) and intuitional (Group 2) planning approaches.

		Group 1				Group 2				Group 2 - Group 1		
Dosimetric Index	Objective	Mean	Std. Deviation	Minimum	Maximum	Mean	Std. Deviation	Minimum	Maximum	Mean Difference	Z Statistic	*p* value
High Risk PTV V100% (%)	≥95%	95.00%	0.00%	95.00%	95.00%	95.25%	0.79%	95.00%	97.50%	0.25%	−1	0.317
Low Risk PTV V100% (%)	≥95%	96.82%	1.81%	94.69%	99.65%	97.39%	1.24%	95.68%	99.37%	0.57%	−1.478	0.139
Brainstem V54Gy (cc)	<0.03 cc	0.07	0.21	0.00	0.68	0.00	0.00	0.00	0.01	−0.07	−1.604	0.109
Spinal Cord V45Gy (cc)	<0.03 cc	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	−1	0.317
Cord PRV V48Gy (cc)	<0.03 cc	0.01	0.04	0.00	0.14	0.00	0.00	0.00	0.00	−0.01	−1.826	0.068
Ipsilateral Parotid Mean (Gy)	<26Gy	2713.69	194.31	2533.50	3188.00	2479.57	128.65	2212.20	2592.60	−234.12	−2.803	0.005
Ipsilateral Parotid V30Gy (%)	<50%	37.0730%	3.19628%	33.37%	43.27%	32.24%	3.98%	24.80%	38.39%	−4.83%	−2.803	0.005
Contralateral Parotid Mean (Gy)	<26Gy	2581.71	183.87	2200.30	2874.40	2373.62	235.84	1939.20	2574.50	−208.09	−2.803	0.005
Contralateral Parotid V30Gy (%)	<50%	34.42%	3.63%	25.80%	37.38%	30.13%	5.68%	21.87%	36.71%	−4.29%	−2.803	0.005
Combined Parotid <20Gy (cc)	≥20cc	28.59	8.35	16.20	45.41	35.07	12.74	16.68	55.67	6.48	−2.803	0.005
Mandible V70Gy (cc)	<0.03 cc	7055.93	462.23	6187.70	7795.00	7009.98	348.03	6447.20	7507.40	−45.95	−1.07	0.285
Constrictors Mean (Gy)	<50%	5706.21	583.27	5057.80	6647.60	5423.23	668.96	4745.20	6502.00	−282.98	−2.803	0.005
Cricopharyngeus Mean (Gy)	<44%	4557.02	911.66	3704.70	6981.30	4391.83	994.61	3423.10	6949.60	−165.19	−1.988	0.047
Ipsilateral Cochlea Mean (Gy)	<45 Gy	1439.71	1357.43	217.10	4969.00	1149.40	1234.04	185.70	4398.70	−290.31	−2.701	0.007
Ipsilateral Cochlea V55Gy (%)	<5%	0.13%	0.42%	0.00%	1.33%	0.19%	0.61%	0.00%	1.92%	0.06%	−1	0.317
Contralateral Cochlea Mean (Gy)	<45 Gy	1636.10	1513.68	189.40	4588.10	1439.93	1347.69	165.00	4374.00	−196.17	−2.191	0.028
Contralateral Cochlea V55Gy (%)	<5%	0.12%	0.37%	0.00%	1.17%	1.08%	3.40%	0.00%	10.76%	0.96%	−1	0.317
Ipsilateral Brachial Plexus Max (Gy)	<66Gy	6623.48	159.19	6372.20	6923.50	6531.60	141.91	6294.50	6824.60	−91.88	−2.497	0.013
Contralateral Brachial Plexus Max (Gy)	<66Gy	6587.51	148.28	6360.10	6799.20	6505.07	87.28	6307.60	6588.00	−82.44	−1.274	0.203
Max Point dose (%)	<110%	109.19%	2.55%	106.75%	114.42%	107.54%	1.32%	105.34%	110.16%	−1.64%	−2.191	0.028
Monitor Units		470.30	76.95	333.00	605.00	862.00	161.11	607.00	1177.00	391.70	−2.803	0.005

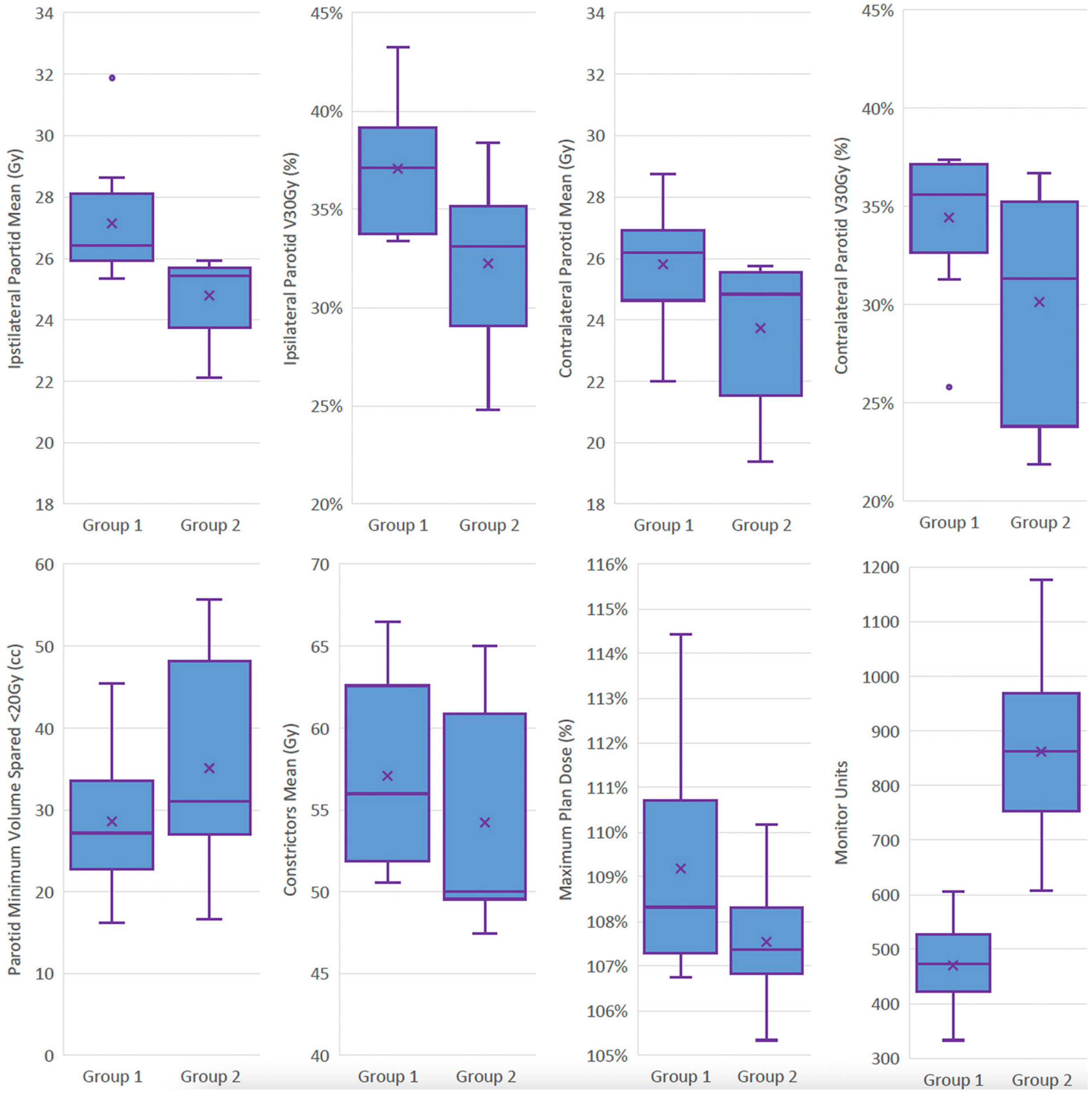

Figure 1. Box-and-whisker plots demonstrating changes in OAR dosimetry with standard (Group 1) and intuitional (Group 2) planning approaches.

observation was not studied in an objective manner. Future study is needed to quantify the organizational and efficiency benefits to this planning approach. Furthermore, the institutional approach requires additional time during treatment to employ an additional arc. Increased treatment time can result in increased patient discomfort, diminished clinical throughput, and potentially increase risk for intrafractional movement [17]. Although the relatively rigid set-up of the head and neck region in conjunction with thermoplastics and other immobilizing devices generally allows for reliable set-up, intrafractional movement can occur and may increase over time [18]. Furthermore, three-arc plans require significantly more monitor units to deliver. However, when considered in the context of patient immobilization and acquisition of images for image-guided radiotherapy (IGRT), the incremental time increase necessitated by the need for an additional treatment arc is minimal, particularly when weighed against the dosimetric benefits observed in this study.

A further limitation of the study is the retrospective nature of the analysis, as well as the inherent limitation in generating treatment plans with the knowledge that they will not be utilized in patient care. It is possible that some of the benefits observed could be secondary to expectancy bias; planners may have spent less time and effort in generating the two-arc plans, knowing that they would not be implemented in the patient's treatment. Though this bias is unavoidable in this type of retrospective analysis, it is worth noting that the three-arc approach is not mandated but continues to be utilized for the vast majority of patients, suggesting it is not overly onerous from a planning perspective. Additionally, the study is limited by the use of a single treatment planning system for a single linear accelerator. Whether these findings would be transferrable to other planning systems or treatment machines remains unknown.

In summary, this beam arrangement represents a simple, reproducible, and easily implemented solution to planning for head and neck cancer patients which may reduce overall planning time and improve OAR dosimetry. This approach requires no additional expertise, equipment, or software beyond what is typically available in most radiation oncology centers. Additional research is warranted to further optimize this technique, quantify possible reductions in planning time, and evaluate this technique with other treatment planning systems and machines.

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Meeting presentation

This study was presented in abstract form at the AHNS/ASCO/ASTRO 2022 Multidisciplinary Head and Neck Cancers Symposium, Phoenix AZ, 24–26 February 2022.

Author contributions

DD and MCR conceived the idea for the study and wrote the initial draft of the manuscript. MCR performed the data analysis. TC, JPS, and JWL provided edits to the initial draft of the manuscript. All authors edited and approved the final draft of the manuscript.

Disclosure statement

Jonathan A. Haas and Jonathan W. Lischalk are paid speakers for Accuray. The remaining authors have no competing interests.

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Data availability statement

The data that support the findings of this study are available from the corresponding author, MCR, upon reasonable request.

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