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A dosimetric comparison of split and open x- jaw methods in volumetric modulated arc therapy for extended target volumes of head and neck cancer

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ABSTRACT

The Treatment Planning System (TPS) in radiotherapy often faces challenges in optimizing techniques for large tumor volumes due to mechanical limitations, such as the over-travel distance of the Multileaf Collimator (MLC). This study compares the dosimetric outcomes of split field and open field techniques in Volumetric Modulated Arc Therapy (VMAT) for carcinoma tongue patients with large target volumes. Twenty-one patients treated with VMAT were evaluated using Eclipse™ TPS. The dosimetric parameters including conformity index, homogeneity index, and dose to Organs at Risk (OAR) were compared between split and open field techniques.

Methods: VMAT plans utilizing two arcs were generated in Eclipse™ TPS with 6MV photon beams on a Truebeam STx Linear accelerator for all patients using both split and open field techniques. In the split field technique, fields were split along the X-Jaw direction. Optimization objectives and collimator angles were kept consistent for both techniques. Dosimetric data were collected and analyzed for conformity index, homogeneity index, and OAR doses.

Results: The study revealed a 3% and 4% difference in homogeneity index, with conformity index values averaging 95% and 97% for split and open fields, respectively. Split field technique demonstrated reduced doses to OARs including Brainstem Dmax (9%), Spinal cord Dmax (6%), PORV cord Dmax (5%), Right Parotid Mean Dose (3%), Left Parotid Mean Dose (3%), Right Parotid (D50%) (5%), and Left Parotid (D50%) (2%), compared to the open field technique. The 50% isodose volume was also 4% lower in the split field technique. While the maximum dose remained identical, differences were observed in homogeneity index, conformity index, maximum dose, and mean dose to OARs.

Conclusion: The split field technique demonstrates superior dosimetry outcomes with reduced doses to OARs compared to the open field technique, albeit with increased treatment time. Thus, the split field technique presents as a favorable option for planning large target volumes in carcinoma tongue cases.

Keywords: spilt x-jaw technique, VMAT, head and neck cancer, large target volumes

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INTRODUCTION

Radiation therapy for cancer treatment relies on advanced technology such as linear accelerators, which aim to deliver precise doses to targeted areas while minimizing exposure to surrounding healthy tissues [1]. Two key mechanical components for beam shaping are the collimator jaws, which create rectangular treatment fields, and the Multi leaf Collimator (MLC), comprised of movable leaves for additional beam shaping. Volumetric Modulated Arc Therapy (VMAT) utilizing MLCs is a sophisticated therapeutic approach that offers improved planning quality and efficiency compared to traditional methods like 3D or fixed Intensity Modulated Radiotherapy (IMRT) [2, 3].

However, there are limitations to VMAT, particularly concerning the maximum X-jaw extent of 15 cm on Varian linear accelerators. This limitation impacts modulation levels, potentially leading to suboptimal target dosage distribution and sparing of Organs at Risk (OAR). Unlike fixed IMRT, VMAT's continuous gantry motion requires single carriage positioning, limiting coverage for large Planning Target Volumes (PTVs) [4-7].

Studies have shown that when the field size exceeds 15 cm, certain areas become inaccessible to modulation by both sides of the MLC, compromising optimization outcomes. Therefore, it's crucial to maintain X-jaw widths at 15 cm or less to ensure adequate dosage coverage and improve OAR avoidance [5, 6].

In the context of treating carcinoma tongue, planning target volumes typically include the Clinical Target Volume (CTV), gross tumor volume, and margins for setup errors and movement uncertainties. Creating PTVs with a 0.5 cm margin around the CTV generates a broad target volume. However, conventional VMAT with standard X-jaw field sizes of 20 cm to 25 cm poses challenges due to MLC constraints [7].

Research by Zhang has identified open and limited X-jaw techniques for VMAT planning strategies. In open X-jaw layouts, the jaw width automatically encompasses the entire target volume, often exceeding the 15 cm MLC constraint and resulting in less modulation and conformity. On the other hand, the limited X-jaw technique, with symmetrical jaw widths of 15 cm, improves modulation, dose distribution, and OAR sparing. Yet, partial coverage of large PTVs remains a concern [8].

To address these challenges, the split X-jaw planning technique divides the open field into two separate fields with overlap, effectively covering the PTV with two treatment arcs spaced 15 cm apart. This method enhances modulation and conformity, as evidenced by promising results in preliminary head and neck treatment planning studies.

MATERIAL AND METHODS

Patient selection & setup

This study comprised twenty-one patients diagnosed with carcinoma of the tongue, selected based on the necessity of a PTV requiring an x-jaw greater than 15 cm for adequate coverage. Patients underwent imaging in the treatment position using a 2.5 mm slice thickness (GE Discovery IQ PET/CT scan) and were immobilized head-first and supine using thermoplastic masks (Orfit Industries, Belgium) along with bite blocks to limit radiation dose to nearby normal tissue. Fiducial markers were applied to the forehead for setup reproducibility, and the scan parameters covered anatomy from the vertex to the Fourth Dorsal Vertebra (D4).

Contouring:

Contouring was performed using the Eclipse™ 15.6 Treatment Planning System (TPS), where target volumes and OARs were defined according to clinical protocol. The radiation oncologist contoured target volumes comprising the gross tumor volume and CTV, with the CTV consistently extended by 0.5 cm to generate the PTV. OARs included the brainstem, spinal cord, and PORV cord, left and right parotid glands, among others.

Treatment plan:

Two treatment plans were created for each patient using Eclipse™ 15.6 TPS, employing open and split x-jaw planning techniques. Patients were prescribed a dose of 54 Gy in 27 fractions on a Varian TrueBeam STx linear accelerator with 6MV beam energies and a maximum dose rate of 600 MU/min. Coplanar dual arcs were utilized in the open-field method, with specific collimator angles chosen to minimize the tongue-and-groove effect. The limited x-jaw method utilized the same isocentre but limited the overall x-jaw extension to a symmetric 15 cm.

In the split x-jaw technique, two arcs were employed with specific collimator settings. The Eclipse Arc Geometry tool was used to widen the jaws to encompass the full PTV. Arc-1 covered the right side of the PTV with a maximum width of 15 cm, while Arc-2 covered the left side similarly. Both VMAT plans were optimized with comparable goals, adhering to protocol limits for OARs and target coverage. The treatment planning goals aimed to achieve target coverage while respecting OAR restrictions (Figures 1 and 2).

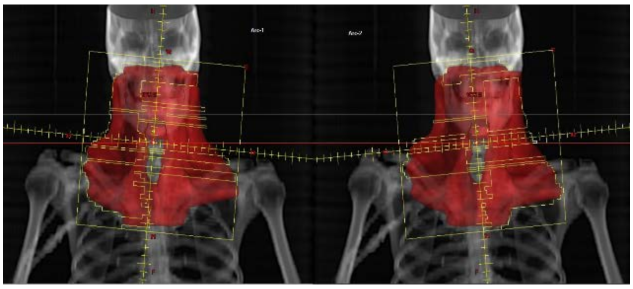

Fig. 1. Open X-jaw field arrangement: Field X= 26.8 cm (Field-1, X1= -13.4, X2=+13.4 & Field-2, X1=-13.4, X2= +12.9)

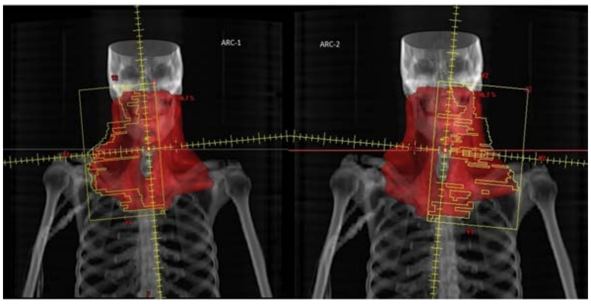

Fig. 2. Split X-jaw field arrangement: Field X=15.0 cm (Field-1, X1= -13.0, X2=+2.0 & Field-2, X1=-2.0, X2=+13.0)

Plan comparison:

The open and split planning methods underwent primary validation based on plan conformity, homogeneity, and OAR sparing. Dosage statistics from the Eclipse TPS were collected and recorded for each plan. Conformity index, derived from the Eclipse TPS, was utilized to assess plan conformity. A conformity index of 1.0 indicates ideal plan conformity, representing the volume enclosed by the prescription isodose region divided by the target volume.

Evaluation indicators for OARs were documented using quantitative data extracted from the Dose-Volume Histogram (DVH), following established guidelines. Secondary comparison data encompassed various criteria, including maximum dose, volumes of the 50% and 105% isodose areas, and total Monitor Units (MUs). Maximum dose for each plan was constrained within the PTV. Volumes of the 50% and 105% isodose areas were measured in cubic Centimeters (cm^3) to evaluate plan conformity. Total MUs were computed by summing the MUs from each arc treatment field within the specified plan. All secondary parameters were recorded based on dosage statistics provided by the Eclipse TPS (Figure 3).

RESULTS

In the entire study cohort, both planning methodologies successfully achieved the delivery of 100% of the prescribed dose to 95%

of the PTV. The open technique, serving as the foundation plan, necessitated multiple optimization iterations to achieve an acceptable dose distribution. It's worth noting that this requirement for multiple optimizations in the open plan does not imply inferior quality compared to the split techniques, as the split techniques would similarly require iterative adjustments if they were employed as the base plan.

Conformity, homogeneity and OAR's sparing

Comparison of the two planning strategies focused on target coverage assessed through plan conformity. The split technique exhibited superior PTV conformity, achieving 97%, whereas the open method achieved 95% conformity. Additionally, the calculated Homogeneity index differed by 3% and 4% between the Split field and open field techniques, respectively (Figure 4). Moreover, the split field technique demonstrated enhanced sparing of OARs. Compared to the open jaw technique, it resulted in reduced doses to the brainstem Dmax by 9%, spinal cord Dmax by 6%, PORV cord Dmax by 5%, right parotid mean dose by 3%, left parotid mean dose by 3%, right parotid (D50%) by 5%, and left parotid (D50%) by 2%. The 50% isodose volume was also 4% lower with the split-field technique.

While the maximal dose remained comparable between the split field and open field techniques, there were slight differences observed in the homogeneity index, conformity index, maximum dose, and mean dose to OARs (Figure 5).

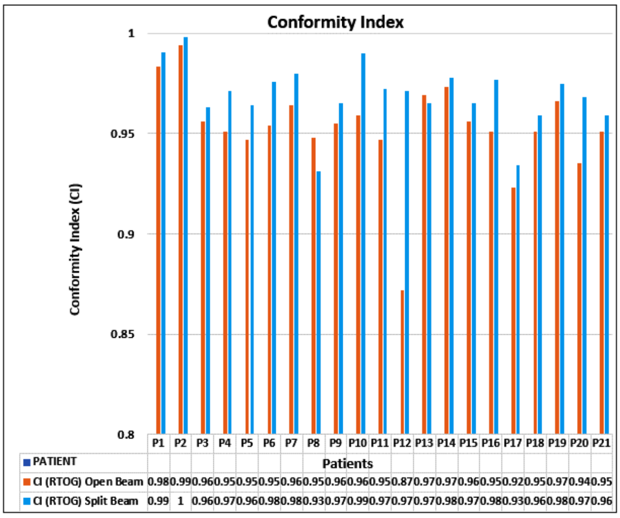

Fig. 3. Comparison of Conformity index between open and split techniques

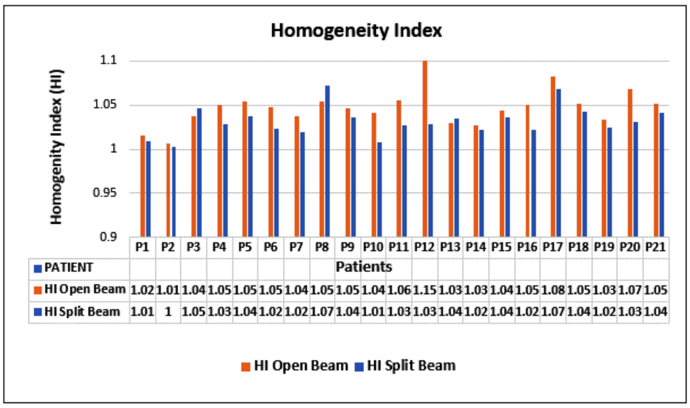

Fig. 4. Comparison of Homogeneity index between open and split techniques

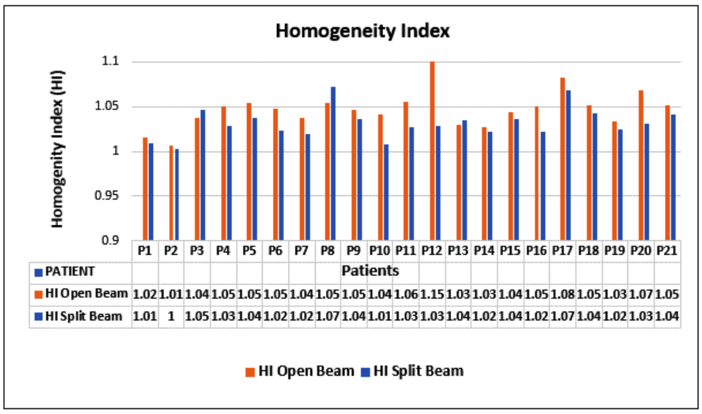

Fig. 5. Comparison of organ at risk dose between open and split techniques

Dose parameters and monitor unit

The split technique consistently yielded the lowest maximum dose across all 21 cases, with a mean of 107.1% ± 0.1%, followed closely by the open technique at 107.2% ± 0.3%. Moreover, the volume of the 105% isodose region was significantly smaller when employing the split planning method, averaging 3.0cc compared to 5.9cc with the open technique. The difference in volume ranged from 0.2 cc to 13.5 cc, with the split plan consistently exhibiting less volume compared to the open plan ($p<0.040$).

Similarly, the volume of the 50% isodose region was notably smaller in the split plans, averaging 2528.5cc compared to 2641.8cc in the open techniques ($p<0.000$). The mean Monitor Units (MUs) in both open and split methods reflected the degree of plan modulation. As modulation increased, MUs also increased, with the split plans exhibiting higher MUs (mean 646.5 ± 65 MU) compared to the open plans (mean 445.0 ± 42 MU) ($p<0.000$).

DISCUSSION

The objective of this retrospective study was to evaluate the efficacy of employing split x-jaw planning with Varian linear accelera-tors to improve plan conformity and reduce OAR dose in PTVs requiring field sizes exceeding the MLC's maximum x-jaw field size of 15 cm. While Varian Medical Systems does not explicitly recommend against improper treatment planning for large PTVs, users are advised to consider the 15 cm modulation constraint. Initial findings from this study build upon the work of Zhang et al., comparing split versus open planning methods, with the split x-jaw method demonstrating superior results.

During this retrospective research, the split x-jaw technique con-sistently exhibited the most favourable plan conformity. Dividing each open field into two arcs and constraining field sizes to 15 cm mitigated the limitations of open planning methods. This ap-proach ensured that the entire PTV remained within the dual arc fields throughout treatment, resulting in improved dose distribu-tion and target coverage.

In contrast, open planning methods, while encompassing the en-tire PTV, utilized field sizes much larger than the MLC's maxi-mum field size of 15 cm, resulting in suboptimal modulation and dose distribution. Additionally, the split beam method offered op-portunities for plan normalization with higher clinical coverage and achieved an average conformity index below 1.0. Regarding OAR sparing, the split technique demonstrated supe-rior performance due to increased modulation, resulting in signifi-cant reductions in dose to critical structures such as the brainstem, spinal cord, PORV cord, and left and right parotids. In contrast, the open method failed to adequately modulate to shield OAR regions outside the MLC leaf width, leading to increased dosage. However, it's important to note that the split-field method is as-sociated with increased MUs and treatment time compared to the open-field method. Patients with difficulties maintaining the setup position for extended periods may not tolerate the split planning method well. Moreover, increased MUs may result in higher doses of low-dose radiation to surrounding normal tissue, potentially in-creasing the risk of secondary malignancies. Nevertheless, despite the greater number of treatment arcs and MUs, the split technique did not pose an increased risk of secondary malignancies. Furthermore, it effectively minimized high-dose areas by delivering the smallest 105% isodose region and the lowest maximum dose.

CONCLUSIONS

The Varian linear accelerators MLCs have a maximum leaf travel of 15 cm in the x-jaw position. However, the conventional open jaw technique, historically employed for treating PTVs larger than 15 cm, faces limitations and requires improvement. Extending the x-jaw beyond the 15 cm limit to encompass the entire PTV, as done in the open x-jaw method, results in inadequate modulation and poses challenges in terms of OAR sparing and conformity. In this study, open methods were contrasted with a split method known as the split x-jaw technique. This approach involves divid-ing open fields into 15 cm x-jaws using two arcs, aiming for en-hanced modulation and full PTV field coverage.

The split beam technique not only offered the opportunity for clinical plan normalization with improved PTV coverage but also achieved an average conformity index below 1.0. Further investigation into achieving conformity index values lower than 1.0 with the split x-jaw planning technique could be valuable. Compared to open techniques, the split method demonstrated superior target dose distributions and effectively spared OARs. Moreover, by reducing the 50% and 105% isodose areas, the split method significantly enhanced plan conformity. Importantly, there was no heightened risk for secondary malignancies associated with the split planning technique when comparing low dosage regions between the two planning methods.

However, a limitation of the study was its small sample size, highlighting the need for future research with a larger study population. Based on the findings of this study and those of Zhang et al., discontinuing the open planning method and focusing on split techniques in future endeavors is recommended. Furthermore, to assess its applicability, the split x-jaw treatment planning technique should be explored in other body regions with substantial PTVs, such as the head and neck, abdomen, and pelvic regions.

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