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Dosimetric Comparison of Volumetric Arc Therapy and Helical Tomotherapy in Locally Advanced Non-Small Cell Lung Cancer

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ABSTRACT

Radiotherapy (RT) in lung cancer emphasizes the use of modern techniques due to the size of the treatment area and doses to critical organs. This study aimed to evaluate dosimetric differences between Helical Tomotherapy (HT) and Volumetric Arc Radiotherapy (VMAT) plans and which technique is more appropriate in patients with stage IIIB inoperable non-small cell lung cancer (NSCLC).

Fifteen patients with stage IIIB inoperable NSCLC and a planning target volume (PTV) >200 cc or length >10 cm, treated between January 2024 and December 2024, were included. A prescription of 60 Gy in 30 fractions was applied. Plans were evaluated using conformity index (CI), homogeneity index (HI), and doses to critical organs.

The median PTV volume was 385 cc (range: 213–615 cc). Both planning techniques covered 98% of the prescribed dose (p = 0.887), but HT demonstrated significantly better HI (p = 0.011). HT also yielded significantly lower doses in total lung V5, contralateral lung V5, heart mean dose, heart V50, and spinal cord max dose. Esophageal doses showed no significant differences. Although dose constraints for the esophagus were met in both planning systems, a lower dose was achieved with HT."

Modern planning systems can achieve desired doses in large volume targets while remaining within dose limits for organs at risk. HT provided significant advantages in critical organ sparing and better homogeneity in dose distribution. The selection of the appropriate technique should be determined based on the characteristics of the tumor and the specific needs of the patient.

Keywords: *Non-small cell lung cancer, radiotherapy, Helical Tomotherapy, VMAT, dosimetric comparison*

INTRODUCTION

Non-small cell lung cancer (NSCLC) accounts for approximately 85% of all lung cancer cases and remains a leading cause of cancer-related mortality worldwide [1,2]. For patients with locally advanced disease (stage III), definitive radiotherapy (RT), often administered concurrently with platinum-based chemotherapy, constitutes the cornerstone of curative-intent treatment [3]. However, radiation delivery to the thoracic region presents substantial challenges due to the complex anatomical relationships, variable tumor volumes, and the close proximity of critical organs-at-risk (OARs), including the lungs, heart, esophagus, and spinal cord. These anatomical constraints necessitate the use of highly conformal and image-guided RT techniques to ensure tumor control while minimizing treatment-related toxicities such as pneumonitis, esophagitis and cardiotoxicity[4,5].

In the context of radiation-induced toxicity, radiation pneumonitis (RP) represents the most significant dose-limiting adverse effect following thoracic irradiation. Symptomatic RP can adversely affect the quality of life and clinical progression, and in some instances, it may be fatal, with an incidence rate ranging from 15% to 45%. However, the comparative contribution of the two radiation modalities, helical tomotherapy (HT) versus intensity-modulated radiation therapy (IMRT), to the risk of RP in lung cancer remains unclear [6].

Advances in radiation technology have enabled the widespread adoption of modern techniques such as HT and VMAT. These modalities offer significantly improved dose conformality and organ sparing compared to conventional three-dimensional conformal radiotherapy (3D-CRT). HT delivers radiation in a helical pattern using continuous gantry rotation combined with couch translation, allowing for highly homogeneous dose distributions [7]. VMAT, in contrast, delivers intensity-modulated radiation through dynamic arc rotations, offering efficient dose sculpting and shorter treatment times [8].

Despite these technological advances, comparative clinical and dosimetric data for HT and VMAT in the context of locally advanced NSCLC are limited. There is no consensus on which technique is most appropriate for NSCLC. Therefore, this study aims to evaluate and compare HT and VMAT treatment plans with regard to target volume coverage, dose homogeneity, conformity indices, and sparing of organs at risk, to better inform the optimal choice of modality for this patient population.

MATERIAL AND METHODS

This retrospective dosimetric study included a total of 15 patients diagnosed with stage IIIB, inoperable NSCLC who were treated between January and December 2024 in our clinic. All patients were selected based on specific inclusion criteria: a PTV greater than 200 cm^3 or a longitudinal tumor extent exceeding 10 cm. Patients had previously undergone thoracic contrast-enhanced four-dimensional computed tomography (4DCT) (Siemens Somotom Flash) simulation in the supine position with appropriate immobilization devices such as wing board to minimize setup uncertainties and motion artifacts. Slice thickness for 4DCT images was 2 mm, and created average images were transferred to both planning systems for evaluation.

For each patient, two different radiotherapy techniques were planned and compared: VMAT and HT. VMAT plans were created using the Eclipse Treatment Planning System (Version 18, Varian Medical Systems, Palo Alto, CA) for delivery on a Varian TrueBeam STX linear accelerator. Two arcs were created by determining the angle according to the tumor location were typically used, and dose optimization was performed using the Photon Optimizer algorithm. HT plans were generated using Volo Ultra module of the Accuray Precision Treatment Planning System (Version 3.3.1.3, Accuray Inc., Sunnyvale, CA) for the Accuray Radixact X9 platform, utilizing a fan-beam helical delivery pattern with 2 cm dynamic jaw movement and 0.287 pitch adjustment. All HT plans were created using the same CT data sets used for VMAT to ensure consistency in anatomical delineation and planning conditions.

Contouring of target volumes and OARs was performed in accordance with RTOG guidelines. The gross tumor volume (GTV) included the primary tumor and involved lymph nodes. The clinical target volume (CTV) was defined by adding 8-10mm margin to the GTV to account for microscopic spread. PTV) was generated by expanding the CTV by 3-5 mm in all directions to compensate for setup uncertainties and respiratory motion.

All plans were normalized such that 95% of the PTV received the prescribed dose of 60 Gy in 30 fractions (2 Gy per fraction). Dose constraints were applied to minimize irradiation of OARs, including the total lung, contralateral lung, heart, esophagus, and spinal cord (Figure1-2).

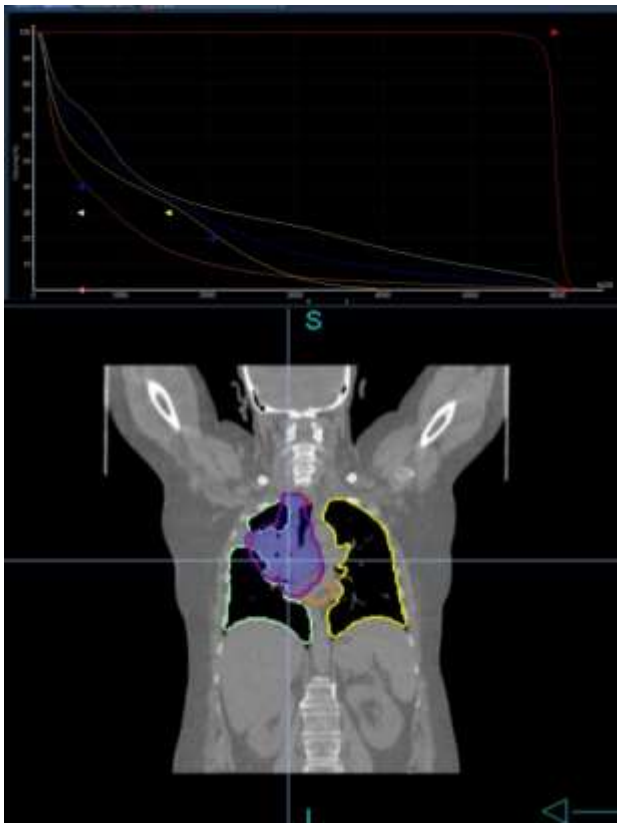

Figure 1: Dose-volume histogram and dose distribution for HT.

Figure 1: Dose-volume histogram and dose distribution for VMAT.

Specific dosimetric parameters included: Conformity Index (CI): A measure of how well the prescribed dose conforms to the shape of the target volume. The RTOG Conformity Index (CI) is defined as: [V PIV /V TV] Where TV is the target volume and PIV is the prescription isodose volume[9]. Homogeneity Index (HI): Used to assess dose uniformity within the PTV. HI = D2-D98/Dp×100; where D2 = minimum dose to 2% of the target volume indicating the "maximum dose", D98 = minimum dose to the 98% of the target volume, indicating the "minimum dose" and Dp = prescribed dose [10]. Total and contralateral lung doses: V5, V20, and mean dose. Heart dose: V50 and mean dose. Esophageal dose: Mean dose, maximum dose, and V60. Spinal cord dose: Maximum point dose. Dose-volume histograms (DVHs) were generated for each plan, and dosimetric parameters were extracted and compared.

Statistical analysis was performed using the Wilcoxon signed-rank test for paired data, and a p-value less than 0.05 was considered statistically significant (Table 1). This methodology allowed for a direct comparison of the two techniques under identical anatomical and volumetric conditions, thereby enhancing the robustness of the dosimetric evaluation.

Table 1. Mean ± standard deviation values of M30 and M65 biochemical parameters obtained in the experimental.

	HT (mean)	VMAT (mean)	
HI	7,65	9,30	P: 0,011
CI	1,15	1,09	P: 0,94
PTV D98 (Gy)	56,44	56,46	P: 0,586
Total Lung V20(%)	24,53	25,46	P: 0,955
Total Lung V5(%)	56,57	62,10	P: 0.003
Total Lung mean(Gy)	13,63	14,24	P: 0,125
Contrlateral Lung V20(%)	11,19	6,75	P: 0.006
Contrlateral Lung V5(%)	44,17	55,02	P: 0,003
Contrlateral Lung mean(Gy)	7,79	7,62	P: 0,670
Spinal cord max (Gy)	14,23	32,18	P: 0,001
Heart V50(%)	1,87	2,61	P: 0,013
Heart mean(Gy)	7,64	11,47	P: 0,004
Esophagus mean(Gy)	18,92	19,91	P: 0,233
Esophagus max(Gy)	58,42	59,78	P: 0,156
Esophagus V60(%)	1,82	4,48	P: 0,272

RESULTS

In the comparative evaluation of dosimetric outcomes between (HT) and VMAT), several statistically significant differences were identified in terms of target coverage, homogeneity, and (OAR) sparing

HT was found to provide significantly better dose homogeneity compared to VMAT, as reflected by a lower HI: 7.6540 vs. 9.3013, p = 0.011). Although

both techniques achieved similarCI) values (1.1553 vs. 1.0980, p = 0.94) and near-identical PTV coverage (PTV98), HT resulted in improved dose uniformity within the target.

Regarding pulmonary dosimetry, HT demonstrated a statistically significant reduction in low-dose lung exposure (Total Lung V5: 56.57% vs. 62.10%, p = 0.003). Additionally, contralateral lung V5 was also significantly lower in HT plans (44.17% vs. 55.02%, p = 0.003), which is critical in sparing normal lung tissue. However, VMAT showed significantly better performance in reducing high-dose exposure to the contralateral lung, as indicated by lower V20 values (6.75% vs. 11.19%, p = 0.006).

The spinal cord maximum dose was markedly lower in HT (14.23 Gy vs. 32.18 Gy, p = 0.001), demonstrating a notable advantage in spinal cord sparing. Similarly, HT resulted in significantly reduced cardiac dose parameters, including heart V50 (1.87% vs. 2.61%, p = 0.013) and mean heart dose (7.65 Gy vs. 11.48 Gy, p = 0.004).

Although esophageal mean and maximum doses were slightly lower in HT, these differences were not statistically significant. The esophagus V60 was also reduced in HT (1.82% vs. 4.49%), but without reaching statistical significance (p = 0.272).

Median PTV volume was 385 cc. Dose coverage for PTV (98%) was achieved in both techniques (p = 0.887). HT plans demonstrated significantly better HI (7.654 vs. 9.301, p = 0.011). Critical organ doses were significantly lower in HT plans for lung V5, heart mean/V50, and spinal cord max dose. Esophageal doses were slightly lower with HT but not statistically significant.

Hence, HT was superior to VMAT in terms of dose homogeneity, reduction of low-dose lung exposure, spinal cord and heart protection, while VMAT provided better sparing of the contralateral lung from high-dose volumes. These findings suggest that the choice of modality may need to be individualized based on the location of the tumor and clinical priorities in OARs sparing.

DISCUSSION

This comparative analysis between HT and VMAT for locally advanced NSCLC reinforces earlier findings, particularly those by Cattaneo et al. [11], who demonstrated that HT outperformed three-dimensional conformal radiotherapy (3D-CRT) in dosimetric quality using advanced planning algorithms. Our study builds upon this by showing that HT not only surpasses traditional 3D-CRT but also delivers superior dose homogeneity (HI: 7.65, p = 0.011) and improved organ-at-risk (OAR) sparing compared to contemporary arc-based VMAT systems.

HT demonstrated more uniform dose distribution and significantly better sparing of critical structures including the spinal cord, heart, and low-dose lung volumes. Conversely, VMAT provided improved protection of the contralateral lung from high-dose exposure, emphasizing the modality's strength in conformality and efficiency. These results partially contrast with those of Xu et al. [12], who reported better conformity and heart sparing with VMAT. Such discrepancies likely reflect differences in contouring techniques, planning objectives, and patient-specific anatomical variations.

Our findings are consistent with previous reports in other thoracic malignancies, particularly the study by Zhang et al. [13], which compared HT and VMAT in malignant pleural mesothelioma. Their analysis also concluded that HT provided superior dose homogeneity and target conformity. Similarly, we observed that HT significantly reduced both total lung V5 and contralateral lung V5, a critical factor in mitigating the risk of radiation-induced pneumonitis. Moreover, HT achieved substantial reductions in spinal cord maximum dose and key cardiac dose parameters (mean heart dose and Heart V50). Zhang et al. likewise reported more favorable spinal cord sparing with HT in complex pleural tumors. This consistent OAR-sparing pattern reinforces HT's capability for precise dose modulation in challenging thoracic settings.

Our study also confirmed that VMAT allows for significantly shorter treatment times. While this enhances patient throughput and minimizes the risk of intra-fractional motion, it must be weighed against potential compromises in dose distribution, particularly when high-precision OAR avoidance is a clinical priority.

Our findings also align with those of Klunklin et al. [14], who demonstrated that both HT and VMAT yielded clinically acceptable plans, with VMAT offering modest improvements in conformity and more efficient delivery times. However, HT maintained robust target coverage and favorable quality assurance results, supporting its reliability in

complex cases. Similarly, Li et al. [15] compared multiple radiation techniques in NSCLC and found that although VMAT achieved the best conformity, it also resulted in the highest low-dose lung exposure. In agreement with their results, our study showed that HT consistently reduced lung V5 and contralateral lung V5, reinforcing its value in protecting healthy lung tissue from scattered radiation.

Temelli et al. [16] examined HT versus a hybrid (3D CRT + VMAT) technique in 15 patients with similar dose prescription, 60 Gy/30 fractions and found that HT achieved better dose homogeneity (lower HI and D_2/D_{98} values), supporting our observation. They also reported lower low-dose lung and heart exposure with the hybrid approach—specifically, mean lung V10 and heart mean dose favored the hybrid plan. In contrast, our analysis demonstrated that HT significantly reduced low-dose lung volumes (Total Lung V5 and contralateral Lung V5) and provided better spinal cord and cardiac sparing compared to full-arc VMAT. Differences between the studies may arise due to the specific hybrid planning techniques, which employed a combined tangent-style 3D+arc method yielding distinct dose distributions compared with pure VMAT. Furthermore, hybrid technique used fewer monitor units and shorter beam-on times than HT.

Taken together, these data reinforce that the choice between HT and VMAT should be individualized based on tumor location, target volume complexity, patient-specific pulmonary reserve, and institutional planning expertise. For example:

- HT may be preferred when low-dose lung sparing, spinal cord protection, or homogeneity within large PTVs is a high priority.

- VMAT may be advantageous where faster treatment times and reduction in high-dose contralateral lung exposure are clinically important.

CONCLUSION

This retrospective dosimetric study demonstrated that HT provides comparable target coverage to VMAT while offering superior dose homogeneity and better sparing of critical organs, including the lungs, heart, and spinal cord, in patients with locally advanced, inoperable stage IIIB non-small cell lung cancer (NSCLC). These dosimetric advantages of HT may translate into clinically meaningful benefits by potentially reducing radiation-induced toxicities and improving patient outcomes.

Although both modalities are clinically viable options, the choice of technique should be individualized based on tumor characteristics and patient-specific anatomy. Given the limitations of this study, including its retrospective design and small sample size, further prospective trials with larger cohorts are warranted to confirm these findings and to assess long-term clinical outcomes such as overall survival, progression-free survival, and quality of life. Also it is advisable to conduct a comparative analysis of the treatment outcomes observed in other centers and to undertake toxicity and survival assessments based on these findings.

Overall, the results support the integration of HT as a valuable treatment modality in the multidisciplinary management of advanced-stage NSCLC, especially in cases with complex tumor geometry or challenging organ-at-risk constraints.

Conflict of Interest

There are no conflicts of interest and no acknowledgements.

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