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Research Article

Comprehensive Evaluation of Treatment Plans in Stereotactic Body Radiation Therapy (SBRT) for Lung Cancer Patients

Ramiser Yanık[1]*, Bahar Dirican[2]

[1]Gülhane Education and Research Hospital, Department of Radiation Oncology, 06010, Ankara-Türkiye
* **Corresponding Author Email:** ramisertanriseven@gmail.com - **ORCID:** 0000-0002-9181-2738

[2]Gülhane Education and Research Hospital, Department of Radiation Oncology, 06010, Ankara-Türkiye
Email: diricanbahar@gmail.com- **ORCID:** 0000-0002-1749-5375

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Abstract: Non-Small Cell Lung Cancer (NSCLC) is a major public health problem and a leading cause of cancer-related deaths. Stereotactic Body Radiotherapy (SBRT) has emerged as a highly precise treatment modality that provides high biologically effective doses (BED) with superior dose compliance, high conformity and sharp dose falloff, and has an important place in the treatment of NSCLC. This study aims to evaluate the SBRT plans for 22 NSCLC patients by assessing the Conformity Index (CI), Heterogeneity Index (HI) and organs at risk (OAR) doses.

Findings demonstrate that SBRT is effective in achieving tumor control in hypoxic and radio resistant tumor regions through precise target coverage and effective intra tumor dose heterogeneity. These features make SBRT a noninvasive and highly effective alternative to surgery for patients with early-stage NSCLC. This study highlights the unique effect of SBRT, a radiotherapy option that reduces doses to organs at risk while improving treatment outcomes, in the treatment of NSCLC and highlights its unique potential in the treatment of NSCLC by evaluating its dosimetric parameters.

1. Introduction

Lung cancer is a leading cause of death worldwide. The therapeutic efficacy of Stereotactic body radiotherapy (SBRT) lies in its ability to deliver uniquely high biologically effective doses (BEDs), while SBRT improves the sharp dose fall-off just outside the target, reducing radiation dose to normal tissues. The aim of this study was to evaluate SBRT treatment plans in non-small cell lung cancer (NSCLC) patients and to examine dosimetric results.Radiation therapy is used for all stages of NSCLC both curative and palliative intention. SBRT demonstrates superior local control and survival outcomes compared to conventional fractionation. It increasingly serves more complex patient segments with a higher risk of treatment-related toxicity [1].SBRT is defined by the American College of Radiology (ACR) and the American Society of Radiation Oncology (ASTRO) as the delivery of fraction-per-fraction radiation doses of 6 Gy or higher in few fractions (1-5 fraction) [2]. SBRT, an ultra-hypo fractionated and highly conformal treatment, limits normal tissue density and provides excellent local tumor control [3]. Appropriate delivery of high BED for lung cancer has been shown to improve the therapeutic ratio and local control rates [4,5].The Radiation Therapy Oncology Group (RTOG) 0236 study showed >90% local control in patients with NSCLC. SBRT increases dose heterogeneity within the target and hot spots within the target facilitate the eradication of radio resistant hypoxic clones in this region. Lung SBRT is also a viable treatment option for a limited number of metastatic lung cases, where secondary cancers have metastasized to the lung from other primary tumor sites [6]. In light of recent scientific developments, SBRT has been included in guidelines as a reliable treatment option for medically inoperable NSCLC patients with primary or metastatic lung lesions. SBRT offers a high local control rate [7,8]. It aims for higher dose conformity, steeper dose gradients around the target volume, and better sparing of adjacent

organs at risk (OARs), and its ability to do so parallels treatment outcomes [9].It exhibits antitumor activity on radio resistant hypoxic clones due to hot spots within the target Compared to conventional radiotherapy, SBRT dose prescription typically relies on low isodoses with minimal or no margin for the penumbra at the target edge. The primary rationale for SBRT is to improve dose fall-off just outside the target volume, thereby enhancing the protection of organs at risk outside the target area. This approach inherently increases dose heterogeneity within the target [10,11].Compared to traditional radiotherapy techniques, SBRT requires specialized equipment, an experienced treatment team, and a higher level of confidence in the accuracy of the entire treatment delivery process [12]. In this study, a comprehensive evaluation of SBRT treatment plans was performed in lung cancer patients using the SBRT technique. The doses received by the PTV and critical organs were examined.

2. Material and Methods

In this study, simulation computed tomography images with motion management were acquired for 22 NSCLC patients who were indicated for treatment with SBRT by their physician. Breath-holding was achieved using the ABC system to minimize tumor motion. The CT images were then imported into the Monaco treatment planning system (TPS) version 15.6. Gross Tumor Volumes (GTV) and Planning Target Volumes (PTV) were created by a radiation oncologist. PTV were generated to account for concerns related to tumor size, location, and motion [13,14]. Basic characteristics of the patients are presented in **Table 1**.

Table 1. *Basic characteristics of the studided NCSLC patients*

	Number
Age (years) Mean±SD Median(Range)	 57±15.0 56 (51.5-72.5)
Location Left lung Right lung	 14 (%63.6) 8 (%36.4)

OARs including GTV, lungs, esophagus, heart, spinal cord, tracheobronchial tree (TBT), ribcage, and proximal bronchial tree (PBT) were delineated. Treatment plans were completed in accordance with the critical organ dose restrictions of the RTOG-0813 [15] and BR-001 [16] protocols, and OARs were evaluated accordingly. The dose limitation protocols for OARs in NSCLC SBRT patients are summarized in **Table 2**.

***Table* 2.** *The dose limitation protocols for OARs*

Organ at Risk (OAR)	**Dose limitation**	**Protocol**
Lungs	V12.5<1500 cc	RTOG-0813
	V13.5<1000 cc	RTOG-0813
	V13.5<37%	BR-001
Esophagus	V27.5<5 cc	RTOG-0813
Heart	V38<0.03 cc	RTOG-0813
	V32<15 cc	BR-001
Spinal cord	Dmax<30 Gy	RTOG-0813
	V22.5<0.25 cc	RTOG-0813
	V13.5<0.5 cc	RTOG-0813
Tracheobronchial Tree (TBT)	V40<0.03 cc	RTOG-0813
	V32<5 cc	RTOG-0813
Rib cage	V57<0.03 cc	BR-001
	V45<5 cc	BR-001
Proximal Bronchial Tree (PBT)	Dmax<40 Gy	BR-001
	V32<0.5 cc	BR-001

The following parameters were assessed: Conformity Index (CI), Heterogeneity Index (HI), Paddick Index (PI), V95, Dmax, Monitor Units (MU), and PTV (cc).

2.1 Study Design, Target Delineation, and Treatment Unit

This study included 22 NSCLC SBRT patients. GTV was less than 15 cc, and the tumor diameter was less than 5 cm. The total dose of 50 Gy was prescribed to the PTV in 5 fractions. Treatment plans were performed using 6 MV x-ray energy for the Elekta Infinity linear accelerator and it was ensured that at least 95% of the PTV received the prescribed dose. To improve movement control and targeting accuracy, the ABC breath-tracking system, 4DCT phased acquisition, and IGRT protocol were employed before treatment delivery [6].

2.2 Treatment Planning

All treatment plans were created using the Monaco TPS with the Monte Carlo algorithm. Each target was treated with the same dose in every plan. Plans were designed using a single full arc on a central plane and two non-coplanar partial arcs. Volumetric Modulated Arc Therapy (VMAT) with full and partial arcs and coplanar/non-coplanar fields was utilized. The Monte Carlo algorithm was specifically used to account for inhomogeneous environments. Treatment plans were generated with 1 mm slice thickness and a high calculation grid spacing of 0.25 cm.

2.3 Deep-Inspiration Breath-Hold (DIBH) – ABC Breath Monitoring System

Patients have their nostrils closed with a plug to ensure that they are not breathing through their nostrils. They breathe through a mouthpiece connected to a flexible tube and a spirometer to monitor their breathing through the mouth. The pneumatic spirometer measures airflow by detecting the pressure difference between the incoming and outgoing air. A computer program records the pressure signal over time, converts it to a digital signal, and creates a visual image on the screen. Its used to prevent treatment errors caused by respiratory motion between simulation CT images and treatment table [17].

2.4 Homogeneity, Heterogeneity Index

RTOG conformity index [18] is calculated by dividing the prescribed treatment volume by the target volume. CI = 1.0 indicates an impossible-perfectly concordant plan and is ideal. The RTOG recommendation for CI is <1.2, with values between 1.2 and 1.5 considered acceptable with minor deviations.Ian Paddick [19] proposed the Paddick Conformity Index, also referred to as the Confirmation Number (CN), defined as the square of the target volume (TV) covered by the prescription isodose volume (PIV) divided by the product of TV and PIV. The ideal value of CN is 1, though it is always <1, with values closer to 1 indicating higher plan quality.Additionally, the heterogeneity index (HI), as defined by RTOG [20], is the ratio of the maximum dose (Dmax) to the prescription dose.

2.5 Plan Delivery Quality Assurance

Delivery Quality Assurance (DQA) is essential before plan acceptance due to the considerable uncertainty associated with a heterogeneous lung target. DQA for each plan was performed using the Matrix QA phantom. The mean gamma analysis (3%, 3 mm) was used for evaluation [21].Gamma Evaluation Scores (GES) were calculated based on a Dose Difference (DD) and a Distance to Agreement (DTA) of 3%, 3 mm, and using a 10% dose threshold. A minimum pass rate of 95% was required.

3. Results and Discussions

PTV parameters were used to assess plan quality. The basic parameters of the studied NSCLC patients, including PTV volume, Monitor Units, V95 (Gy), and Dmax, are summarized in **Table 3**. Doses to critical organs, including the spinal cord, esophagus, brachial plexus, and heart, were recorded. Target coverage parameters (CI, HI, CN) for the studied NSCLC patients are presented in **Table 4**, while OAR dose results for the 22 NSCLC SBRT treatment plans are detailed in **Table 5**. The planning target volume coverage (V95%) was consistently above 95%, with CI values ranging between 1.0 and 1.2, reflecting high dose conformity. The HI values demonstrated effective intratumoral dose heterogeneity, with maximum dose values concentrated in the tumor core, targeting hypoxic, radio resistant tumor clones [16]. **Figures** provide insights into the practical implementation of SBRT:**Figure 1** illustrates the dose distribution for two non-coplanar partial arcs, optimizing coverage. These results validate the treatment design's ability to maintain precise

coverage while ensuring adequate dose intensification within the tumor. **Figure 2** demonstrates the full arc plan's uniform dose distribution, emphasizing organ-at-risk sparing. **Figure 3** compares dose distributions for left and right lung targets, showcasing isotropic dose gradients [18].

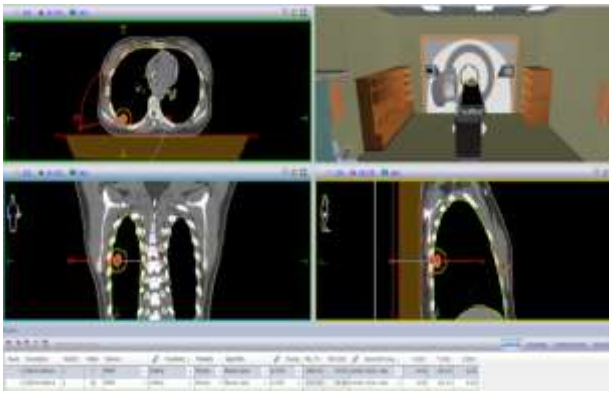

Figure 1. *2 partial arc*

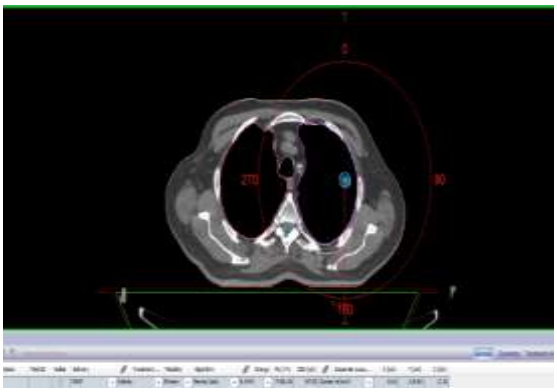

Figure 2. *Full arc*

Table 3. *Basic Paramaters of the Studided NCSLC Patients*

	Mean±SD
PTV volume (cc)	5.88±3.7
Monitor unit (MU)	4874.2±1471
V95 (Gy)	49.9±0.3
Dmax (Gy)	54.0±0.56

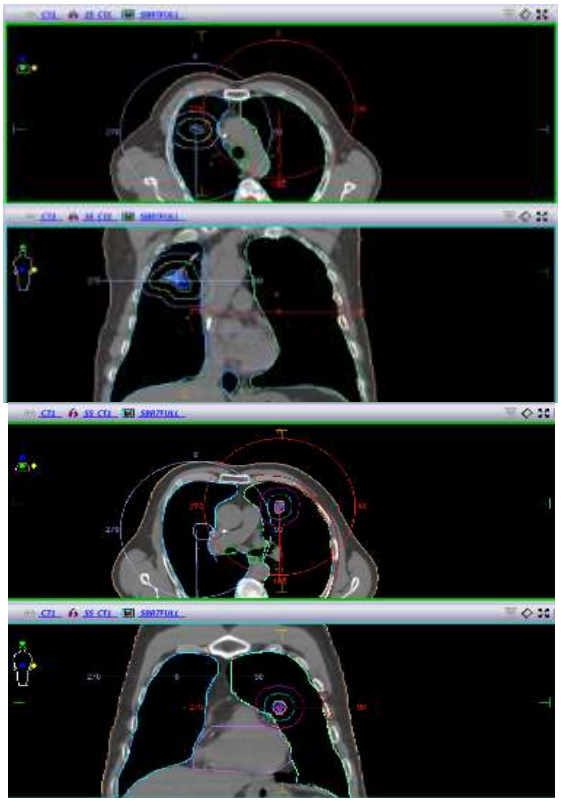

Figure 3. *Right target-Left target*

Table 4. *Target Coverage Parameters of the Studided NCSLC Patients*

Parameter	Mean±SD	Median (Range)
Conformity Index (CI)	1.03±0,05	1.04 (0,96-1,11)
Homogeneity Index (HI)	1.09±0,5	1.08 (1.0-1,18)
Paddick Conformity Number (CN)	0.92±0.06	0.88 (0.86-1.11)

Table 5. Total OAR Results

Criteria	**CASE 1**	**CASE 2**	**CASE 3**	**CASE 4**	**CASE 5**	**CASE 6**	**CASE 7**	**CASE 8**	**CASE 9**	**CASE 10**	**CASE 11**

PTV volume (cc)	14.6	6.471	2.971	7.664	5.661	7.855	5.909	3.608	9.612	2.304	3.239
Monitor Unit (MU)	3097	5769	4506	2976	3863	4195	5195	5186	4569	4569	3144
V95(Gy)	50	49.1	50.4	49.4	50.4	50	50	50	50	50	49.5
Dmax(Gy)	53.5	54.4	53.4	53.9	54	53.4	54.7	53.62	54.7	53.3	54.4
Lungs V12.5<1500cc	243.7	132.2	145.4	94.7	368.5	409.1	211.4	283.6	175.8	217.0	119.9
V13.5<1000cc	237.8	118.7	129.9	85.7	342.2	363.0	191.9	260.2	160.7	198.2	111.2
V13.5<37%	5.48	2.41	2.9	1.38	11.9	9.5	4.7	3.94	8.6	3	2.35
Esophagus V27.5<5cc	0	0	0.8	0	1.4	0	0	0	0	0	0
Heart V38<0.03cc	0	0	0	0	2.0	0	0	0	0	0	0
V32<15cc	0	0	0	0	5.4	0	0	0	0	0	0
Spinal cord Dmax<30Gy	9.9	3.9	7.7	6	10.4	24.7	8.4	14.4	0.3	14	10.7
V22.5<0.25cc	0	0	0	0	0	0.1	0	0	0	0	0
V13.5<0.5cc	0	0	0	0	0	5.3	0	0.3	0	0	0

Criteria	**case 12**	**case 13**	**case 14**	**case 15**	**case 16**	**case 17**	**case 18**	**case 19**	**case 20**	**case 21**	**case 22**
PTV volume (cc)	2.173	2.679	1.488	5.476	2.963	7.828	6.224	14.56	2.527	3.056	10.4
Monitor Unit (MU)	3197	4470	6334	7050	7149	7268	2236	7154	4021	5984	5300
V95(Gy)	50	50	50	49.8	50	49.5	49.7	50.1	50.3	50	50
Dmax(Gy)	53.3	54	53.8	54.6	54.6	54.7	53.8	54.9	54.7	54.8	53.3
Lungs											
V12.5<1500cc	102.3	332.7	278.3	436.3	179.6	372.6	150.8	291.2	237.6	385	380
V13.5<1000cc	91.1	295.9	245.8	382.4	153	349.7	140.8	271.1	209.7	340	343
V13.5<37%	1.7	7.4	5.9	6.54	2.62	6.8	4.87	5.28	4.25	4.9	5.0
Esophagus											

V27.5<5cc	0	0	0	0	0	0	0	0	0.8	0	0
Heart											
V38<0.03cc	0	0	0	1.9	0	0	0	0.3	0	0	0
V32<15cc	0	0	0	4.3	0	0	0	1.1	0	0	0
Spinal cord											
Dmax<30Gy	0.6	10.3	10.2	0.5	0.3	9.8	0.8	0.7	0.7	17.7	17.6
V22.5<0.25cc	0	0	0	0	0	0	0	0	0	0	0
V13.5<0.5cc	0	0	0	0	0	0	0	0	0	0	0

The findings highlight the capacity of stereotactic body radiation therapy to achieve precise tumor targeting with minimal risky organ exposure. High conformity (CI < 1.2) and controlled heterogeneity (HI < 1.5) are consistent with established criteria for stereotactic body radiation therapy quality. Sharp dose fall-off improves safety by reducing toxicity in critical structures such as the lungs and spinal cord [19].

Future research is expected to address challenges such as the integration of advanced imaging modalities in radiotherapy techniques using intra-fraction tumor motion and magnetic resonance guidance to improve sensitivity. Furthermore, long-term outcomes and comparative studies with surgical interventions are needed to solidify the role of stereotactic body radiation therapy in the treatment of non-small cell lung cancer [20, 21]. Investigation of adaptive radiotherapy modalities may further improve dosimetric accuracy, especially in tumors with irregular geometries or locations.

4. Conclusions

Lung SBRT is a safe and effective method to treat tumors in NSCLC patients with high radiation doses [22].Organs at Risk Doses: Dose limits for the lungs, esophagus, heart, and spinal cord were within the limits specified in the RTOG-0813 [15] and BR-001 [16] protocols due to the sharp dose fall-off beyond the target volume. The dose distribution gradient outside the PTV was isotropic and a uniform dose fall-off was achieved just from the surface of the PTV. As the irradiated volume decreased, the OARs, especially the intact lung, received lower doses. A decrease in toxicity was observed as the irradiated volume decreased [5].The proven success of these protocols provides a strong basis for further research to expand the clinical applications of stereotactic body radiation therapy in oncology. The SBRT technique meets the criteria outlined in the guidelines and is a highly useful and promising method for treating lung tumors.

Author Statements:

- **Ethical approval:** This study does not involve human participants or animal subjects; therefore, ethical approval was not required.
- **Conflict of interest:** The authors declare no conflicts of interest.
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