Evaluation of 3D CRT, IMRT and SBRT Treatment Planning Techniques in Lung Cancer Irradiation: A Case Study
Eyob Mathias, B.S. R.T.(T) and Nishele Lenards, M.S., CMD, R.T.(R)(T), FAAMD
*Medical Dosimetry Program at the University of Wisconsin - La Crosse, WI; Geisinger Wyoming Valley, Department of Radiation Oncology, Henry Cancer Center, Wilkes Barre, PA

Abstract:
Introduction: The purpose of this study was to evaluate, compare, and contrast three-dimensional conformal radiation therapy (3D-CRT), intensity modulated radiation therapy (IMRT) and stereotactic body radiation therapy (SBRT) treatment planning techniques for the treatment of lung cancer. The efficacy in meeting multiple normal tissue constraints while maximizing tumor coverage was evaluated.

Case Description: Three patients with lung cancer were compared for the case study. For patient 1, an IMRT technique was used to plan a right upper lobe (RUL) lung region. For Patient 2, SBRT technique was used to plan a RUL lung region. For patient 3, 3D-CRT was used to plan a RUL lung lesion.

Conclusion: All plans were evaluated by the radiation oncologist for adequate dose coverage to the gross tumor volume (GTV). Each plan was evaluated based on the dose delivered to the organs at risk (OR). The dose to the heart, spinal cord and total lung volume were compared between the three treatment techniques. The limitation of this case study was the difference in tumor size among the 3 patients. According to this case study, 3D-CRT forward planning technique illustrated a preferable minimal dose to the OR while maximizing tumor coverage for RUL lung lesion. Further investigation with increased study population is needed to support the findings of this case study.

Key Words: Lung cancer, IMRT, 3D-CRT, SBRT

Introduction: Lung cancer radiation therapy treatment represents an ongoing challenge for radiation oncologists around the world.\(^1\) The radiation therapy approach in the treatment of lung cancer has consisted of different techniques that have been developed to provide a conformal dose.
distribution within the target volume and spare the surrounding critical structures. Now that most RT facilities have the technology to perform IMRT and 3D-CRT planning, the options for beam arrangement as well as treatment field numbers have significantly multiplied. Complex treatment techniques in lung irradiation consist of stereotactic body radiation therapy (SBRT) and inverse-planned IMRT. Intensity modulated radiation therapy offers wide range of gantry angle options in addition to improving dose homogeneity and decreased OR irradiation. The major feature that separates SBRT from 3D-CRT or IMRT is the delivery of large doses in a few fractions, which results in a high biological effective dose. In order to minimize the normal tissue toxicity, conformation of high doses to the target and rapid fall-off doses away from the target is critical. The use of IMRT for lung cancer has demonstrated that OR such as the heart and lungs can be spared more effectively. This study will demonstrate 3 different techniques of RT used to treat adenocarcinoma of the lung to determine their efficacy in meeting multiple normal-tissue constraints while maximizing tumor coverage.

Case Description

Patient selection & setup

A total of three patients were selected based on diagnosis, tumor location, cancer stage and treatment planning technique. All patients were diagnosed with a non-operable lung tumor with or without hilar and mediastinal lymph node involvement.

Patient 1 had a significant history of chronic obstructive pulmonary disease (COPD) and was diagnosed with stage IIIA adenocarcinoma of the lung. The patient was to receive IMRT and then be re-evaluated for potential tumor resection depending on the tumor size reduction. Patient 2 had a tumor measuring 1.9 cm located in the apex of the RUL lung adjacent to the pleura laterally near the chest wall. The patient had a T1N0M0 lesion but due to his medical comorbidities, he was at poor risk for anesthesia and lobectomy; therefore the patient received SBRT. Patient 3 was diagnosed with recurrent stage IIIB, RUL lung cancer with mediastinal lymphadenopathy. The lesion was located near the apex of the right lung and measured about 2 cm. The plan was local control using 3D-CRT technique.

Each patient underwent a CT simulation scan. A Med-Tec wing board immobilization device was utilized during the simulation process. All 3 patients were simulated in supine position with both arms raised and positioned above the head on the angled board. All patients had radiopaque
markers placed according to sagittal and lateral lasers to aid with patient positioning and reproducibility.

**Target delineation**
All patients underwent a CT simulation scan and a Fluorodeoxyglucose positron emission tomography (FDG-PET) scan to aid with the contouring process. Target delineation was completed using the Medical Image Merge (MIM) deformable fusion version 6 software. Using this software, the medical dosimetrist localized the position of the tumor and the radiation oncologist contoured the GTV on the PET-CT fused image (Figure 1). After the radiation oncologist contoured the GTV, the medical dosimetrist contoured the heart, spinal cord and a combined total lung volume (minus the GTV) for each patient.

**Treatment planning**
The dose prescription and planning parameters for the 3 cases are presented in Table 2. For patient 1, a radiation treatment plan was designed for the patient to receive a total of 50.4 Gy at 1.8 Gy for 28 fractions using a 9 field IMRT technique (Figure 2). For a patient receiving 50.4 Gy to the entire tumor and lymph node volume, a conedown dose of up to 66 Gy to the GTV is permitted. The physician scheduled to re-evaluate the tumor after receiving 50.4 Gy and depending on the tumor size reduction, tumor resection was a possibility. The objective of using an IMRT technique was to reduce the radiation toxicity to the total lung volume while maintaining a homogeneous dose distribution throughout the treatment volume. The radiation oncologist recommended 0.7 mm margin for the planning target volume (PTV). Furthermore, the dosimetrist contoured the left lung, right lung, heart, esophagus, carina, spinal cord and three rings around the PTV. These contours was used as objectives during plan optimization. A 6 MV beam energy was selected. The TPS utilized the direct machine parameter optimization (DMPO) feature to achieve the IMRT objectives of the plan and the dose volume histogram showed an acceptable OR dose (Figure 4).

For patient 2, a Varian trilogy linear accelerator machine with 6 MV beam energy was used to plan the 8 beam SBRT technique with a prescription dose of 50 Gy in 5 fractions (Table 2). The medical dosimetrist placed an isocenter in the RUL lung region approximately 4.0 cm right from the vertebral body (Figure 5). The placement of the isocenter corresponded approximately to the mid-plane depth of the target volume (Figure 6). Each of these field apertures had a multi-leaf
collimator (MLC) blocking pattern to define the treatment field. A challenge was observed when the tumor presented slight motion during respiration. The variation in clinical target volume (CTV) size and position due to respiratory motion or organ filling is generally accounted for by an internal margin added to the CTV, resulting in the internal target volume (ITV). The dose contraints for each OR was entered in the inverse planning window (Figure 7). Typical SBRT margins for defining the minimal distance separating the CTV and PTV surfaces are 0.5 cm in the axial planes (ant/post) and 1.0 cm in the inferior/superior directions for treatments that were performed in conditions that suppressed respiratory motion. Dose prescriptions in SBRT are often specified at low isodoses e.g., 80% isodose and with small or no margins for beam penumbra at the target edge, as compared to traditional radiation therapy. The rationale is to improve dose fall-off outside of the targeted volume and help spare nearby OR (Figure 8). This practice increases dose heterogeneity within the target.

For patient 3, the objective was local control using 3D-CRT irradiation technique and to achieve adequate dose distribution to the GTV while minimizing the dose to the critical structures. Three beams of left anterior oblique (LAO), right posterior oblique (RPO) and right anterior oblique (RAO) were utilized. The LAO and RPO beams consisted of 35.3% and 31.37% beam weighting respectively. A 33.33% beam weight was assigned for the RAO field. The medical dosimetrist assigned a prescription dose of 45 Gy in 25 fractions and employed the collapsed cone convolution superimposition (CCCS) algorithm calculation method to generate a treatment plan (Table 2). The challenge was observed when the tumor presented slight motion during respiration. This obstacle limited the medical dosimetrist to accurately deliver the prescribed dose exactly to the assigned target volume without expanding the treatment field and encompassing more lung tissue. A margin of approximately 1.5 cm was given in order to account for breathing motion as well as patient setup variation.

Plan analysis & Evaluation

In all the three cases, the medical dosimetrist optimized the prescription dose to the medially located lung tumor volume. Each treatment technique employed one or more of these components to optimize the treatment plan which included: beam energies, beam weighting and an IMRT optimizing module in the TPS. Once the adequate prescription dose coverage was achieved, the medical dosimetrist reviewed the dose to the OR, the isodose lines, and the DVH
for each treatment. A summary of the \( D_{\text{max}} \) to the heart and the volume of heart receiving 30 Gy (\( V_{30} \)), and the volume of the total lung dose receiving 20 Gy (\( V_{20} \)) are presented in Table 2.

For Patient 1, the evaluation of the IMRT technique illustrated a much better conformity and dose coverage to the RUL lung GTV. The OR on the DVH reflected the Dmax of the heart was 51.5 Gy, \( V_{30} \) was 1\%, and the total lung \( V_{20} \) was 30\% (Table 3). The \( V_{20} \) for the total lung is higher in this case because the GTV volume is relatively larger than the other two cases. The prescription was normalized to the 98\% isodose line to achieve adequate prescription coverage and a homogenous dose distribution throughout the PTV with a hotspot of 108\%. The total lung \( V_{20} \) objective was not achievable due to the relatively higher GTV volume. Although the total lung \( V_{20} \) exceeded the left lung \( V_{20} \) by less than 5\% (Table 3).

For patient 2, the evaluation of the SBRT treatment technique showed an excellent critical structures dose sparing. The OR on the DVH reported the Dmax of the heart was 0 cGy and the total lung \( V_{20} \) was less than 10\% (Figure 10). The prescription was normalized to 80\%. This plan utilized eight beams to achieve a homogeneous dose distribution throughout the target volume with a hotspot of 102\%.

For patient 3, the evaluation of the 3D-CRT treatment planning technique helped to achieve adequate prescription dose coverage to the RUL lung GTV with only 101\% hotspot (Figures 8 & 9). The OR on the DVH reflected the heart Dmax was 33Gy and the \( V_{30} \) was 5\% and the total lung \( V_{20} \) was less than 15\% (Table 3). The prescription for this plan was normalized to 97\%.

**Conclusion**

The limitation of this case study is the difference in tumor size among the 3 patients (Table 1). The evaluation of the SBRT technique illustrated a much better conformity and dose coverage to the RUL lung GTV. The DVH demonstrated a significant reduction in the \( V_{20} \) total lung, spinal cord dose and heart dose (Figure 10). However, this treatment planning technique is only applicable for a smaller tumor size. The 3D-CRT treatment technique utilized for patient 2 is a preferable alternative to IMRT and parallel opposed technique. The use of 3D-CRT, particularly with only 3 to 4 beam angles, has the ability to reduce normal-tissue toxicity, but has limited potential for dose escalation beyond the current standard in node-positive patients. IMRT is of
limited additional value (compared to 3D-CRT) in node-negative cases, but is beneficial in node-positive cases and in cases with target volumes close to the heart.

The challenges that a medical dosimetrist encounters in many lung cancer treatment planning cases are mainly respiratory motion, daily setup errors and sometimes the size of the GTV limiting the number of beam angles that can be used. The most important obstacle in achieving the maximum dose deposition for lung tumors is the lung itself. It is a very important concern in lung irradiation treatment planning to achieve less than 30% volume of the total lung receive 20Gy or less. In all the three case studies, the \( V_{20} \) for the total lung volume was 30% or less. The 3D-CRT forward planning technique illustrated an excellent \( V_{20} \) value for the total lung volume, but when creating such plans a large separation between the medial and lateral tangential beams may be important to reduce the overall hotspot within the treatment volume and evenly distribute the dose using beam weighting factor. It is also important for the medical dosimetrist to consider supine versus prone positioning to achieve an acceptable dose distribution and limit the dose to critical structures and attain superior treatment outcome. According to this case study, the 3D-CRT technique yields a better conformal plan, homogeneous dose distribution and can be delivered efficiently with promising outcomes. Further investigation with larger patient population is warranted to support the findings of this case study.
References


Figure 1. Patient 1, fused TPCT and CT/PET image.
Figure 2. Patient 1, IMRT (98% isodose line represented by the pink line)
Figure 3. Patient 1, Isodose distribution (green = 20\%, orange = 50\%, yellow = 80\%, blue = 90\%, green 95\%, pink = 97\%) and 3D beams eye view (BEV)
Figure 4. Patient 1, DVH
Figure 5. Patient 2, Digitally reconstructed radiograph (DRR), Isocenter position.
Figure 6. Patient 2, Isodose distribution (Aquamarine = 102%, Green = 95%, Blue = 90%, Yellow = 80%, Orange = 50%, Forest green = 20%)
Figure 7. Inverse planning window. Dose constraints to the PTV and each OR
Figure 8. Patient 2, Dose Volume Histogram
Figure 9. Patient 3, Isodose distribution transverse view.
Figure 10. Patient 3, DVH
<table>
<thead>
<tr>
<th>Case</th>
<th>Clinical Stage</th>
<th>TNM</th>
<th>Location</th>
<th>Composite GTV\text{\textsubscript{primary}} Volume (cm\textsuperscript{3})</th>
<th>Composite GTV\text{\textsubscript{nodal}} Volume (cm\textsuperscript{2})</th>
<th>Respiratory motion on fluoroscopy (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IIIA</td>
<td>T1bN2M0</td>
<td>RUL</td>
<td>4.9</td>
<td>1.8</td>
<td>1.9 R/L, 1.4 A/P, 7 S/I</td>
</tr>
<tr>
<td>2</td>
<td>II</td>
<td>T1N0M0</td>
<td>RUL</td>
<td>1.7</td>
<td>0</td>
<td>0.6 R/L, 0.5 A/P, 0.5 S/I</td>
</tr>
<tr>
<td>3</td>
<td>IIIB</td>
<td>T2N0M0</td>
<td>RUL</td>
<td>3.5</td>
<td>0</td>
<td>1.8 R/L, 1.7 A/P, 1.2 S/I</td>
</tr>
</tbody>
</table>

Table 1. Clinical Patient characteristics
Table 2. Prescription and Treatment Planning Parameters

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Patient 1</th>
<th>Patient 2</th>
<th>Patient 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site</td>
<td>RUL</td>
<td>RUL</td>
<td>RUL</td>
</tr>
</tbody>
</table>

**Prescription**

<table>
<thead>
<tr>
<th>Beam Energy</th>
<th>6MV</th>
<th>6MV</th>
<th>6MV &amp; 15MV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dose to Left Breast Volume</td>
<td>50.4Gy in 28 fractions 1.8Gy/fraction</td>
<td>50Gy in 5 fractions 1000cGy/fraction</td>
<td>45Gy in 25 fractions 1.8Gy/fraction</td>
</tr>
</tbody>
</table>

**Planning Technique**

| IMRT        | SBRT       | 3D-CRT    |

**Treatment Planning Parameters**

<table>
<thead>
<tr>
<th>Beam Arrangements</th>
<th>9 co-planar beams</th>
<th>8 beams SBRT</th>
<th>Left anterior oblique (RPO), right posterior oblique (LPO) and right anterior oblique (RAO) beam.</th>
</tr>
</thead>
</table>

Table 2. Prescription and Treatment Planning Parameters
<table>
<thead>
<tr>
<th>Patient 1</th>
<th>Patient 2</th>
<th>Patient 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>IMRT</td>
<td>SBRT</td>
<td>3DCRT Supine</td>
</tr>
<tr>
<td>D_{max} (Gy)</td>
<td>Heart V_{30}</td>
<td>Total lung V_{20} (%)</td>
</tr>
<tr>
<td>32.2</td>
<td>63</td>
<td>10%</td>
</tr>
<tr>
<td>1%</td>
<td>0%</td>
<td>30%</td>
</tr>
</tbody>
</table>

Table 3: Plan Analysis and Evaluation.