International Journal of Cancer Therapy and Oncology
www.ijcto.org

Dosimetric analysis of intensity modulated radiotherapy (IMRT) and three dimensional conformal radiotherapy (3DCRT) for treatment of non-small cell lung cancer: A comparative study

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Received February 24, 2015; Revised June 11, 2015; Accepted July 15, 2015; Published Online August 20, 2015

Original Article

Abstract

Purpose: The purpose of this study is to analyze and compare the dosimetric parameters of three dimensional conformal radiotherapy (3DCRT) and intensity modulated radiotherapy (IMRT) in selected non-small cell lung cancer (NSCLC) cases. **Methods:** Ten patients with inoperable NSCLC were selected for this study. The 3DCRT and IMRT plans were generated for all patients following Radiation Therapy Oncology Group (RTOG) guidelines. Generated plans were then compared on the basis of planning target volume (PTV) coverage, dose delivered to organs at risk, homogeneity index (HI), and conformity index (CI) for the prescribed dose (PD) of 50 Gy in 25 fractions. **Results:** The mean D_{95} and D_{99} (dose to the 95% and 99% volume) for the PTV were found better in the 3DCRT plans compared to the ones in the IMRT plans. On an average, the volume receiving 20 Gy (V_{20}) of contralateral lung was 2.91% and 3.03% in the 3DCRT and IMRT plans, respectively. The D_{mean} of contralateral lung was 3.17 Gy (3DCRT) versus 4.2 Gy (IMRT), whereas the D_{mean} of ipsilateral lung was 12.69 Gy (3DCRT) and 13.82 Gy (IMRT). The V_{20} of ipsilateral lung was found to be slightly lower in the 3DCRT (25.67%) when compared to the IMRT (30.50%). The dose to the heart was comparable in the 3DCRT and IMRT plans (mean dose: 4.42 Gy versus 4.48 Gy; D_{33}: 3.77 Gy versus and 4.02 Gy). For the spinal cord, the D_{max} was found to be lower in the 3DCRT plans (18.40 Gy) when compared to the IMRT plans (25.49 Gy). The HI was 1.08 versus 1.41 in the 3DCRT and IMRT plans, respectively. The CI was identical (1.67) in both sets of plans. **Conclusion:** Based on the results of this study, the PTV coverage was found to be slightly better in the 3DCRT plans when compared to the one in the IMRT plans. On average, the dose to the organs at risk were found to be comparable.

Keywords: Intensity Modulated Radiotherapy; Non-Small Cell Lung Cancer; Three Dimensional Conformal Radiotherapy

Introduction

Radiotherapy is an integral part of non-small cell lung cancer (NSCLC) management and using this therapy the main aim is to treat patient with less complications. The modern radiotherapy has evolved from hand-drawn delineation of target on patient body to three dimensional reconstructions of computed tomography (CT) images with the help of advance computer algorithm. In the early 1990s, three dimensional conformal radiation therapy (3DCRT) using CT images was standard method to deliver radiation using a set of intersecting beams of two dimensional shapes, from which three dimensional high dose region of approximately tumor shape can be achieved to treat the cancer.

The more advance technology intensity modulated radiation therapy (IMRT) was innovated in the late 1990s. In IMRT, the intensity of each beam is modified with the help of multi leaf collimators (MLC) according to the shape of the tumor. With this technique any tumor shaped can be acquired having sudden dose fall outside the region of interest. The use of IMRT technique increased over the last decade but there are certain limitations of this technique, IMRT plans are complex and inappropriate where intrafractional motion of the target is large, such as in lung tumors.[1]

Recent developments in image guided radiotherapy (IGRT) are leading in a new era of radiotherapy for lung tumor. IGRT is the modern technique, which is more accurate when there is an organ motion during treatment such as lung tumor. IGRT involves real time imaging of target and helps to individualize radiotherapy by accounting tumor motion. It has got ability of high precision dose delivery and real-time knowledge of the target volume location. IGRT has initiated the exploration of new indications for radiotherapy.

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***Cite this article as**: Bagdare P, Gurjar OP, Shrivastav G, Bhandari V, Gupta KL. Dosimetric analysis of intensity modulated radiotherapy (IMRT) and three dimensional conformal radiotherapy (3DCRT) for treatment of non-small cell lung cancer: A comparative study. Int J Cancer Ther Oncol 2015; 3(3):3323.*
***DOI:**10.14319/ijcto.33.23*

 ISSN 2330-4049

In case of NSCLC, 3DCRT is being used since long time but IMRT and IGRT have been advocated always superior technique to further decrease the volume of normal tissue exposed to high doses of radiation.[2,3] Respiratory motion alters the dose distributions actually delivered while treating patients from those predicted by plans based on static CT scans.[4] Thus the modulated dose distribution within the volume by IMRT or 3DCRT planned on stationary CT images is matter of concern compare to IGRT where uniform dose is delivered in whole treatment volume using real time images of target during treatment. Although the IGRT is more accurate technique compared to 3DCRT and IMRT, but still its use is limited due to many factors such as accessibility of technology, financial considerations, etc. Thus, 3DCRT or IMRT is used in most of the radiotherapy centers in the developing countries. As lung tumor motion may cause significant degree of dose deviation and uncertainty, the under dosing to the target volume is likely, thus resulting adverse effects on normal tissues in IMRT as compared to 3DCRT if any gated system is not used for the IMRT. This study aims to evaluate the 3DCRT and IMRT planning techniques for the selected NSCLC patients.

Methods and Materials

CT simulation

In the present study, ten inoperable patients diagnosed with NSCLC were selected. Thermoplastic sheet (Orfit) was used for each patient to immobilize the site of interest. Siemens SOMATOM Definition AS scanner (Siemens Medical Systems, Germany) was utilized for the CT scan of the patients and the CT images of 3 mm slice thickness were acquired for each patient in supine position. The CT images were transferred to the Eclipse treatment planning system (TPS), version 8.9 (Varian Medical Systems, Palo Alto, CA). The gross tumor volume (GTV), clinical tumor volume (CTV), planning target volume (PTV) and organs at risk (OARs) were delineated on the CT images following the International Commission on Radiation Units and Measurements report 83 (ICRU 83).[5] The size of PTV varied from 163 cm^3 to 241.7 cm^3 with a mean value of 202.35 cm^3. The 3DCRT as well as IMRT plans for all the cases were created on the same CT data set. All the plans were done for 50 Gy in 25 fractions (#) with 2 Gy/# and five fractions per week.

Treatment planning

Treatment plans were executed by high energy medical linear accelerator (LA) Clinac DMX (Varian Medical Systems, Palo Alto, CA) having 6 and 15 MV photon energies. It is equipped with Millennium 80 MLC having 40 pairs of leaves and leaf width projected at isocenter is 1 cm. The 3DCRT plans were generated by using two to five coplanar fields at desired gantry angles. Wedges of suitable angle were also used in some plans to get desired dose distribution. All 3DCRT plans were generated by using 6 MV, 15 MV or combination of both the photon energies. By using only low energy (6 MV), it was not possible to achieve desired dose distribution inside the PTV in some of the 3DCRT plans, and thus the combination of low (6 MV) and high (15 MV) energy was used in such plans. Hot spots, cold spots, and dose homogeneity were managed by increasing and decreasing monitoring units (MU) of particular fields.

IMRT plans were generated by using coplanar fields of suitable gantry angles.[6] Desired PTV coverage was achieved by 6 MV only. Thus, 15 MV or combination of 6 and 15 MV was not used. Two fields at single gantry angle were also used in some of the plans because of a large target volume if field size exceeded more than 14.5 cm in x-direction and it splits into two fields automatically.[7] The splitting is because of the limitation that is present in MLC, where the maximum distance between the most retracted and extended MLC cannot be more than 14.5 cm. Dose constraints and adequate weights for the OARs and target volumes were given to the TPS to obtained optimum IMRT plans. Dose volume optimizer (DVO) was used for plan optimization and doses were calculated by using anisotropic analytical algorithm (AAA) with 0.25 cm dose calculation grid size.

Plan analysis

The IMRT and 3DCRT plans were evaluated and compared on the basis of dosimetric parameters viz., target coverage, doses to OARs, homogeneity index (HI) and conformity index (CI). HI and CI were calculated by using following formulae;[8]

$$HI = \frac{D_5}{D_{95}}$$

where, D_5 is dose to 5% volume of PTV and D_{95} is dose to 95% volume of PTV.

$$CI = \frac{\text{Volume receiving 95\% of Prescribed Dose}}{\text{PTV}}$$

Statistical analyses of the data sets were done to determine the statistical difference between 3DCRT and IMRT. The p-values were calculated by using unpaired t-test for all the data sets.

Results

The detailed results are given in **Table 1**. **Figure 1** shows the dose distribution on CT image for (a) 3DCRT and (b) IMRT done for one of the selected patients. The mean dose to 95% (D_{95}) and 99% (D_{99}) of PTV was 96.50% (Standard deviation (SD): 1.48) and 94.45% (SD: 2.02) for 3DCRT and 94.76% (SD: 2.07) and 90.49% (SD: 4.02) for IMRT, respectively.

 ISSN 2330-4049

TABLE 1: Dosimetric data of three dimensional conformal radiotherapy (3DCRT) and intensity modulated radiotherapy (IMRT) for ten patients in the case of NASLC

Patient No.		PTV coverage		Epsilateral lung		Contralateral lung		Heart			Spinal cord	HI	CI
		$D_{95\%}$ (%of PD)	$D_{99\%}$ (%of PD)	V_{20} (%)	D_{mean} (Gy)	(V_{20}) (%)	D_{mean} (Gy)	$D_{33\%}$ (Gy)	$D_{67\%}$ (Gy)	D_{mean} (Gy)	D_{max} (Gy)		
1	3DCRT	99.24	98.27	19.60	9.36	0	0.28	0.37	0.22	0.34	6.62	1.06	2.24
	IMRT	96.10	94.67	27.85	13.15	0	2.85	0.97	0.47	1.01	20.22	2.90	2.90
2	3DCRT	96	94.37	38.74	17.97	1.81	4.81	6.63	1.62	8.25	34.57	1.05	1.70
	IMRT	96.22	92.67	48.06	19.91	7.25	6.57	4.83	2.29	6.04	33.19	1.06	1.86
3	3DCRT	95.40	93	18.85	9.03	0	1.29	7.12	5.21	7.96	0.65	1.01	1.23
	IMRT	91.6	84	9.34	6.08	0	1.33	9.11	5.06	10.14	5.15	1.15	1.04
4	3DCRT	95.12	92.05	20.71	11.58	7.87	4.81	0.91	0.54	0.94	20.75	1.09	1.55
	IMRT	93.76	89.81	28.82	12.74	2.19	4.79	1.35	0.67	1.20	33.74	1.12	1.22
5	3DCRT	96.46	95.56	39.04	18.03	1.95	4.99	7.02	1.97	8.90	35.87	1.10	1.82
	IMRT	97.02	93.89	49.00	20.02	8.13	7.03	5.86	2.89	7.12	34.22	1.19	1.92
6	3DCRT	95.92	94.17	38.12	17.66	1.51	4.12	6.42	1.40	8.12	34.02	1.01	1.60
	IMRT	96.58	91.93	48.00	19.02	7.05	6.17	4.70	2.10	5.00	33.00	1.06	1.81
7	3DCRT	95.32	92.5	18.05	9.00	0	1.09	7.02	5.01	7.42	1.55	1.08	1.20
	IMRT	91.2	83	9.04	6.00	0	1.20	9.00	5.00	9.96	5.10	1.12	1.12
8	3DCRT	98.16	94.25	23.81	13.25	8.08	5.25	1.00	0.73	1.01	23.13	1.19	1.77
	IMRT	95.96	91.32	29.22	15.42	3.19	5.09	1.93	0.97	2.12	37.53	1.20	1.52
9	3DCRT	98.13	97.15	18.96	9.10	0	0.19	0.26	0.21	0.30	5.92	1.03	1.92
	IMRT	95.35	93.67	26.79	12.98	0	2.12	0.87	0.40	0.99	18.94	2.1	2.0
10	3DCRT	95.24	93.17	20.79	11.96	7.90	4.89	0.92	0.56	0.99	20.82	1.10	1.58
	IMRT	93.82	89.90	28.85	12.85	2.53	4.85	1.57	0.77	1.23	33.82	1.19	1.29
Mean	3DCRT	96.50	94.45	25.67	12.69	2.91	3.17	3.77	1.78	4.42	18.40	1.08	1.67
	IMRT	94.76	90.49	30.50	13.82	3.03	4.2	4.02	2.06	4.48	25.49	1.41	1.67
SD	3DCRT	1.48	2.02	9.09	3.86	3.56	2.16	3.26	1.87	3.93	13.90	0.05	0.31
	IMRT	2.07	4.02	14.50	5.05	3.29	2.17	3.20	1.78	3.69	12.36	0.61	0.56
***p*-value**		**0.04***	**0.01***	**0.38**	**0.58**	**0.97**	**0.30**	**0.86**	**0.70**	**0.97**	**0.24**	**0.10**	**0.97**

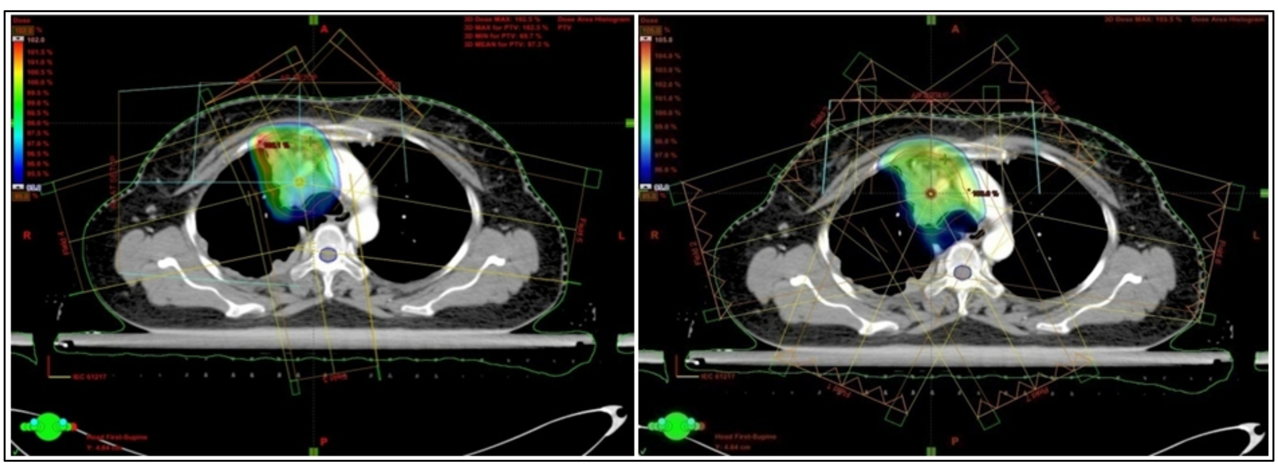

FIG. 1: Dose distribution on CT slices for (a) 3DCRT and (b) IMRT plan.

On an average of all the patients, volume of contralateral lung receiving 20 Gy (V_{20}) was 2.91% (SD: 3.56) and 3.03% (SD: 3.29), D_{mean} of contralateral lung was 3.17 Gy (SD: 2.15) and 4.2 Gy (SD: 2.17), V_{20} of ipsilateral lung was 25.67% (SD: 9.08) and 30.50% (SD: 14.50) and D_{mean} of ipsilateral lung was 12.69 Gy (SD: 3.86) and 13.82 Gy (SD: 5.04) in 3DCRT and IMRT, respectively. D_{33} of heart was 3.77 Gy (SD: 3.26) and 4.02 Gy (SD: 3.20), D_{67} of heart was 1.78 Gy (SD: 1.87) and 2.06 Gy (SD: 1.78) and D_{mean} of heart was 4.42 Gy (SD: 3.93) and 4.48 Gy (SD: 3.69) in 3DCRT and IMRT respectively. D_{max} to spinal cord was 18.40 Gy (SD: 13.90) and 25.49 Gy (SD: 12.36) in 3DCRT and IMRT, respectively.

HI was 1.08 (SD: 0.05) and 1.409 (SD: 0.61) and CI was 1.67 (SD: 0.31) and 1.67 (SD: 0.57) in 3DCRT and IMRT respectively.

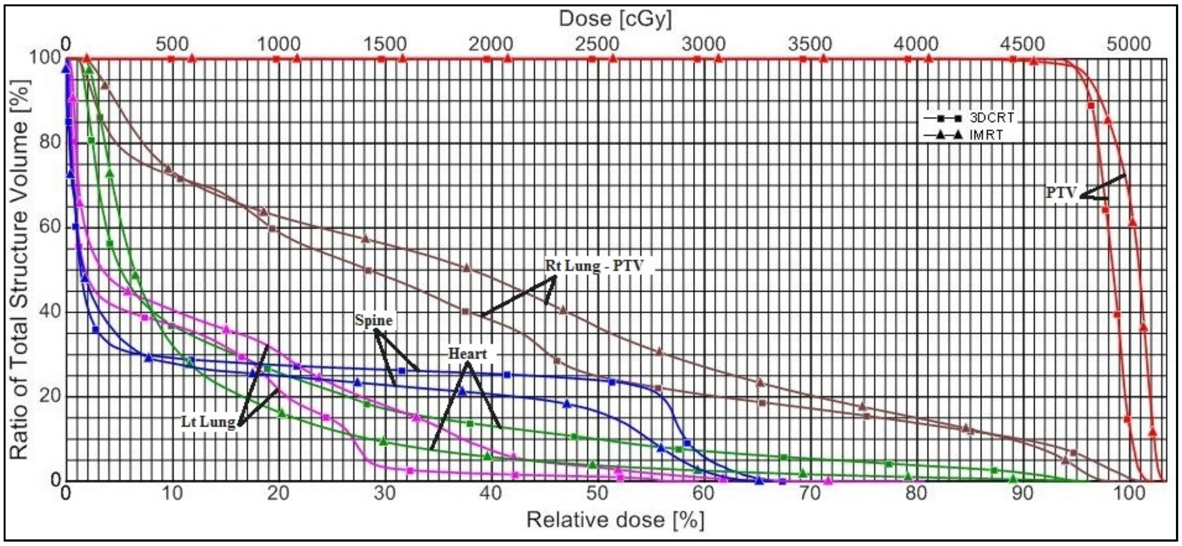

FIG.2: Comparison of dose volume histogram (DVH) for 3DCRT and IMRT plan.

Discussion

From the **Table 1**, it can be concluded that the $D_{95\%}$ and $D_{99\%}$ of PTV in 3DCRT plans had better coverage than that in IMRT and the *p*-values 0.044 and 0.012 showed the statistical significant difference for both the techniques. The *p*-values calculated for critical organs such as contractual lung for V_{20}, and D_{mean} were 0.97 and 0.302, for heart $D_{33\%}$, $D_{67\%}$ and $D_{mean\%}$ were 0.86, 0.70, and 0.97 and for the spinal cord $D_{max\%}$ was 0.24 respectively. All the *p*-values for the OARs were > 0.05, which indicates non-significant difference in the doses to the OARs in both the techniques although the doses to the OARs were lower in some of the 3DCRT plans while higher in other 3DCRT plans when compared to the IMRT. **Figure 2** shows the comparative dose volume histogram for the 3DCRT and IMRT done for one of the selected case which indicates that the PTV coverage was better in the 3DCRT than in the IMRT as well as lower hot spot in the 3DCRT. Dose to ipsilateral lung and contralateral lung in the 3DCRT was slightly less than the ones in the IMRT.

Treatment planning algorithm plays a crucial role for dose calculations though the advance algorithm based on Monte Carlo is more accurate but it has got its own limitations. Recently, a new dose calculation algorithm called Acuros XB (AXB) has been introduced within the Eclipse TPS, and the AXB is considered similar to Monte Carlo. A number of researchers have already presented that the AXB is more accurate algorithm compare to others such as AAA.[9,10] Superposition-convolution based algorithms such as AAA which is more accurate compared to pencil beam convolution (PBC) can also be used for dose calculations. AAA has separate modeling for primary photons, scattered photons and contaminant electrons for dose calculation.[11,12] In this study, the 3DCRT and IMRT plans were generated using AAA since AXB was not available in our TPS during the time of study. However, Rana *et al.* [9] and Ojala *et al.* [10] have recommended to use AXB instead of AAA for dose calculations when low density media such as lung tissue is involved along the photon beam path. The use of accurate dose calculation algorithm is important for the lung cancer to ensure sufficient dose coverage. Recently, there is a significant interest in using proton therapy for the cancer treatment since particle therapy offers localized dose deposition with no exist deposition. The proton therapy can potential provide dosimetric advantages over conventional photon therapy such as IMRT.[13,14]

Conclusion

Based on the results of this study, the PTV coverage was found to be slightly better in the 3DCRT plans when compared to the one in the IMRT plans. On average, the dose to the organs at risk were found to be comparable. Since there is a possibility of lung tumor motion during the treatment, 3DCRT, which is cost effective and requires less treatment time, can be preferred over IMRT in some of the NSCLC cases in this study.

Conflict of interest

The authors declare that they have no conflicts of interest. The authors alone are responsible for the content and writing of the paper.

Acknowledgment

We would like to express our thanks to Director, Roentgen Oncologic Solutions Pvt. Ltd. and Chairman, Sri Aurobindo Institute of Medical Sciences for permitting and encouraging the study.

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