Original Article

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Dosimetric comparison of helical tomotherapy and hybrid (3DCRT-VMAT) technique for locally advanced non-small cell lung cancer

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Abstract

Aim: The purpose of the present study is to compare hybrid [three-dimensional conformal radiation therapy-volumetric-modulated arc therapy (3DCRT-VMAT)] and helical tomotherapy (HT) techniques in terms of both planning target volume (PTV) and organs at risk (OARs) in the plans we made in locally advanced non-small cell lung cancer (NSCLC) patients
Material and methods: Radiotherapy was planned for 15 locally advanced NSCLC patients with 2 different techniques. Large tumours with positive mediastinal lymph nodes were preferred. The prescription dose was determined as 60 Gy at 30 fractions.
Results: Mean PTV volume was 602·5 cc (range: 265–1461). Mean total lung volume was 4264 cc (range: 1885–6803). Homogeneity index, D_{mean}, D_{max}, D_2 and V_{105} were found to be lower in HT, V_{100}, total monitor units (MU) and total beam on time were found to be lower in the hybrid plan. Total lung D_{mean} was found to be 17 Gy in both techniques. V_{10} value was 42·85 in the hybrid plan and 48·67 in HT ($p = 0.037$). Heart D_{mean} was 14·5 Gy in the hybrid plan and 18·7 in HT ($p < 0.001$), and V_{30} values were 18·1 and 22·9, respectively ($p = 0.009$).
Conclusion: Suitable dose coverage and OAR doses can be provided with both techniques. Especially the opposite lung, heart and oesophagus doses can be kept lower with the hybrid plan, and lower MU and shorter beam on time can be provided.

Introduction

About 30% of non-small cell lung cancer (NSCLC) cases are evaluated as locally advanced at the time of diagnosis.[1] This definition includes a broad spectrum. While defining T3–T4 and N2–N3 disease, TNMs (8th edition)[2] other than stage 3 A–B are also generally defined in stage 3C (T3–T4 and N3).[2] Chemoradiotherapy (CRT) is often used in the treatment of locally advanced NSCLC.[3]

The lung itself is sensitive to radiation, and in applying radiotherapy to the thorax region, it is difficult to give the desired dose to planning target volume (PTV) without exceeding the dose to organs at risk (OARs) due to the close proximity of these organs, such as the spinal cord, oesophagus and heart.[4] Therefore, modern techniques such as three-dimensional conformal radiation therapy (3DCRT), intensity-modulated radiation therapy (IMRT), volumetric-modulated arc therapy (VMAT) and helical tomotherapy (HT) are used to overcome these problems.

Compared to 3DCRT, IMRT was found superior in terms of dose conformity and OARs.[5] VMAT has better conformal target coverage than IMRT and provides lower doses in OARs, lower monitor units (MU) and shorter treatment time.[6] HT, another novel approach of IMRT that can deliver radiotherapy (RT) with rotational fields, is increasingly used in lung cancer.[7]

In our study, we wanted to undertake a dosimetric comparison of hybrid (3DCRT-VMAT) and HT techniques in terms of both PTV coverage and the doses received by the OARs in locally advanced NSCLC patients.

Patients and Methods

Patient selection

This was a retrospective study of 15 patients who received radiotherapy between January 2019 and December 2019 in our institution with thoracic radiotherapy for locally advanced NSCLC. Including criteria were having a large sized tumour and positive mediastinal lymph nodes.

Simulation and contouring of targets and OARs

Computed tomography (CT) datasets with a 3-mm slice thickness was taken from all patients in supine position and hands raised above the head at the T-board from C2–C3 level to L3–L4 level. The scans were performed under free breathing.

The images were sent to Velocity Contouring Station (version 2·8·1, the USA). Clinical target volume (CTV) and OARs were contoured by the same radiation oncologist in line with The Radiation Therapy Oncology Group (RTOG) Atlas.[8] The CTV was defined as the gross tumour volume +0·5 cm margin. OARs dose constrains were determined based on the RTOG 1306 study. Dose constrains were as follows: lungs: $V_{20} \leq 37\%$, mean dose ≤ 20 Gy; spinal Cord: 0·03 cc $\leq 50·5$ Gy; heart: $V_{60} < 1/3$, $V_{45} < 2/3$, $V_{40} < 100\%$; oesophagus: mean dose ≤ 34 Gy.[9]

Treatment planning

PTV was obtained by adding 1 cm margin to the CTV. Prescription dose was determined as 60 Gy at 30 fractions. Dose calculation was normalised to cover 95% of the PTV. A volume of 0·03 cc within any PTV should not receive >110% of the prescribed dose. No more than 0·03 cc of PTV received <93% of its prescribed dose. None of the 0·03 cc or more volumes except for PTV were allowed to receive >110% of the prescribed dose of PTV.

Varian Eclipse planning system (version 13·7-Varian Medical Systems, Palo Alto, the USA) was used in hybrid planning, and the Tomotherapy Planning System (Hi-Art Tomotherapy, version 5·1·2, Accuray, Madison, WI, the USA) was used in HT planning. For hybrid plans, the structures contoured at Velocity Contouring Station were transferred to the Eclipse Planning System DICOM (Digital Imaging and Communication in Medicine) format.

The Isocenter was determined as the midpoint of the PTV volume. Anisotropic analytical algorithm photon dose calculation algorithm was used for VMAT plans. Maximum dose rate was 600 MU/min for the VMAT plan and 400 MU/min for the 3DCRT. The dose calculation grid was 2·5 mm.

In VMAT plans, two half 180° arcs or two full 360° arcs, depending on target localisation, were used. In all 3DCRT plans, two opposing fields were used. PO (Photon Optimizer version 13·7) algorithm was used for optimised leaf position, dose rate and gantry speed. The collimator was rotated 30°, 90° and 330° to reduce overlapping tongue and groove effects.

In hybrid-VMAT techniques, 120-leaf (central 20 cm of field uses 0·5-cm-wide leaves, outer field uses 1-cm-wide leaves) dynamic multi-leaf collimator was used. The maximum leaf speed was 2·5 cm/s. Then, 6 MV energy was used in all VMAT plans; 15 MV energy was used in all conformal plans.

For HT plans, a field width of 2·5 cm, pitch value of 0·287, modulation factor of 3 and fine dose calculation grid was used. Then, 6 MV energy was used in all HT plans.

Evaluation tools

Plan evaluation was performed by examining all CT slides one by one and by examining the dose-volume histogram (DVH) isodose curves. Sample isodose curve is shown in Figure 1.

The homogeneity index (HI) was calculated as HI = D_2-D_{98}/D_p, where D_2 is the minimum dose to 2% of the target volume, D_{98} is the minimum dose to the 98% of the target volume and D_p is the prescribed dose. This is the most commonly used formula in literature. Equation 1 shows that lower HI values exude a more homogeneous target dose.[10]

The conformity index (CI) was calculated as:

$$CI = (\text{Cover Factor}) \times (\text{Spill Factor}) = \frac{V95PTV}{VPTV} \times \frac{V95PTV}{V95BODY}$$

where V_{95PTV} and V_{95body} are the volumes of the PTV and body, respectively, receiving at least 95% of the prescription dose, and V_{PTV} is the volume of the PTV. The CI equal to 1 correlated with the ideal dose coverage or high conformity.[11]

The integral dose was defined as mean dose (Gy) × volume (L).[12]

Results

Of our patients, 14 were male and 1 was female. The mean age was found to be 66 years (range: 53–76). Mean PTV volume was 602·5 cc (range: 265–1461). Mean total lung volume was 4264 cc (range: 1885–6803). Patient characteristics are shown in Table 1.

There was no difference between CI. While HI, D_{mean}, D_{max}, D_2 and V_{105} were found to be lower in HT, V_{100}, total MU and total beam on time were found to be lower in the hybrid plan. PTV coverage and treatment parameters are shown in Table 2.

Total lung

D_{mean} was found to be 17 Gy in both techniques. V_{10} value was 42·85 in the hybrid plan and 48·67 in HT ($p = 0.037$). The other parameters were found to be similar.

Ipsilateral lung

D_{mean} was 27 Gy in the hybrid plan and 25 Gy in HT ($p = 0.005$), and V_{20} doses were 53·8 and 49·3, respectively ($p = 0.029$). V_{30} doses were 44·04 and 37·02, respectively ($p = 0.004$).

Contralateral lung

V_{20} value was 9·3 in the hybrid plan and 14·4 in HT ($p = 0.019$). D_{mean}, V_{10} and V_{30} values were statistically lower in the hybrid plan. V5 value was also lower in the hybrid plan, but no statistically significant difference was found.

Heart

D_{mean} was 14·5 Gy in the hybrid plan and 18·7 in HT ($p < 0.001$), and V_{30} values were 18·1 and 22·9, respectively ($p = 0.009$). No statistically significant difference was found in the other parameters.

Spinal cord

D_{max} was 42·2 Gy in the hybrid plan and 41·4 ($p = 0.680$) in HT.

Oesophagus

D_{mean} was 23 in the hybrid plan and 27·6 in HT ($p < 0.001$), and the V_{35} values were 33·7 and 40·6, respectively ($p < 0.001$). V_{40} and V_{60} values were lower in the hybrid plan, while D_{max} was similar in both techniques.

OARs doses are shown in Table 3.

Statistical method

Data are represented by mean and standard deviation. Comparisons between two methods were performed by paired samples t-test. In all analyses, significance level was considered as 0·05. IBM SPSS Statistics for Windows version 22·0 (NY, USA) was used for the analysis.
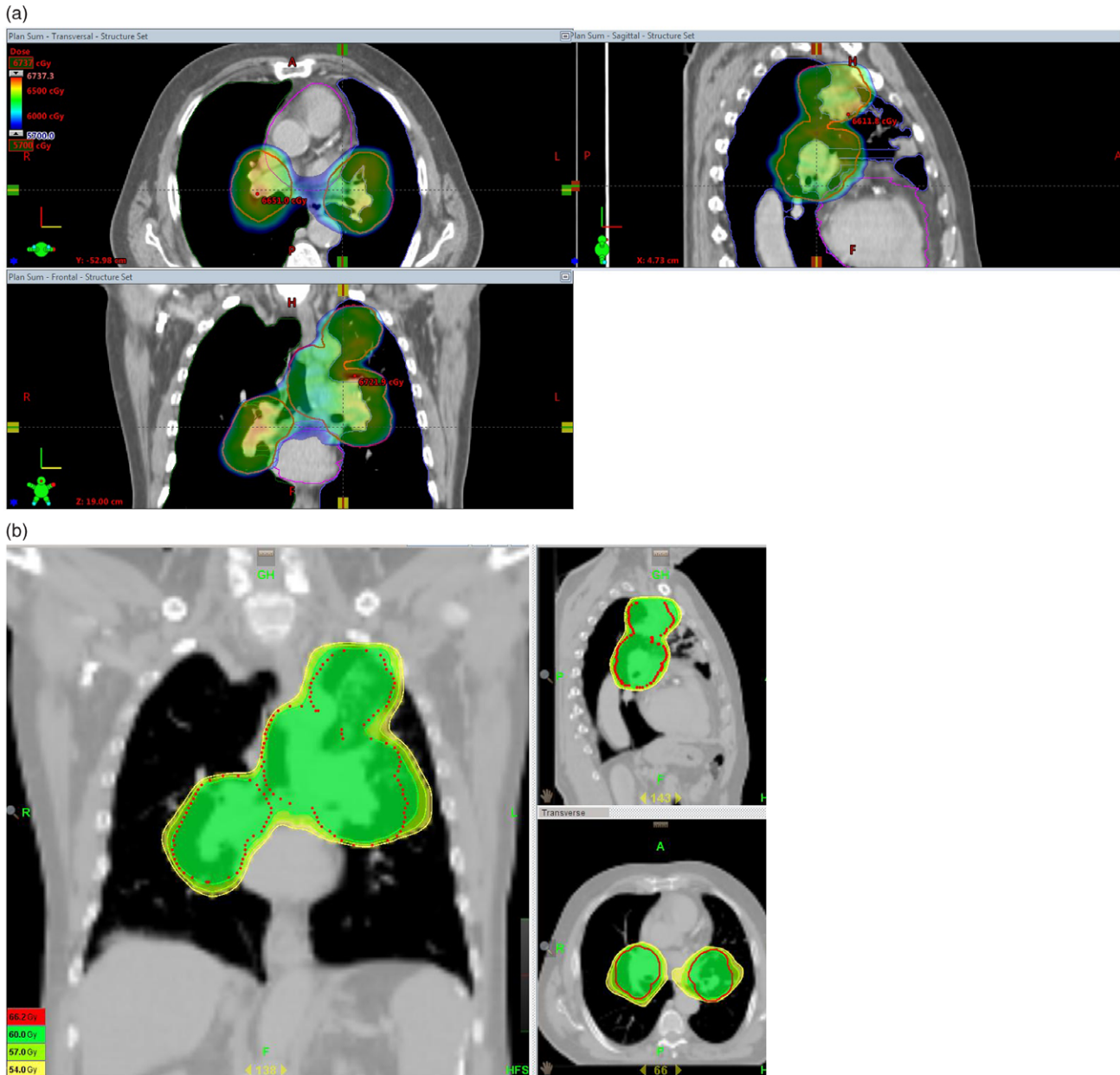
(a)

(b)

Figure 1. Isodose curves of one patient in axial-sagittal and coronal section for (a) hybrid plan; (b) helical tomotehrapy plan.

Discussion

In our study, 2 different treatment plans (hybrid-VMAT and HT) of 15 patients diagnosed with locally advanced NSCLC were compared. The plans made with both techniques are suitable for treatment. HT achieved better HI, higher V_{100} (%) and lower V_{105} (%). However, total MU and beam on time were found to be higher in HT.

Total lung V_{20} and the mean lung dose are the best known parameters for radiation pneumonia.[13] When the V_{20} value was kept below 20%, symptomatic pneumonia risk was 18%, and fatal pneumonia risk was 0%, and when the V_{20} value exceeded 30%, symptomatic pneumonia risk and fatal pneumonia risk increased to 32·6% and 2·9%, respectively.[14] In the study of Kristensen et al., 10 Gy total lung volume was found significant in terms of radiation pneumonia. Median V_{10} value was 60·3% in patients

who developed pneumonia and 52·6% in those who did not develop pneumonia ($p = 0·02$).[15] In our study, lung parameters were suitable for dose constrains, and total lung V_{10} value was 42·8 in the hybrid plan and 48·6 in HT ($p = 0·037$). The other parameters were similar. In the hybrid plans, the opposite lung D_{mean}, V_{10}, V_{20} and V_{30} values were lower than HT. Due to the mutually conformal areas, the opposite lung could be better protected. In a similar dosimetric study, HT was compared with VMAT and IMRT. Compared to IMRT, mean lung V_{20} and V_{30} values were lower in HT, but no difference was found between HT and VMAT (V_{20}:21·8%, 22·2%, 24·2%, respectively; V_{30}:15%, 15·7%, 16·7%, respectively). Since the mean PTV volume in the study was quite low compared to our PTV volume, the lung values were higher in our study (312 cc versus 602·5 cc).[16]

Cardiac toxicity due to RT is a major problem, and cardiac doses should be kept as low as possible. According to the available

Table 1. Patient characteristics

Patients	Age	Sex	Histology	Primary tumour location	T stage	N stage	PTV volume(cc)	Total lung volume (cc)
1	66	M	SCC	Left upper lobe	4	2	403·19	6158
2	53	M	AC	Right middle lobe	4	2	780·70	3512·50
3	58	M	SCC	Right lower lobe	4	2	1461·1	6803·6
4	64	M	SCC	Right upper lobe	4	2	815·6	3750
5	71	M	SCC	Left upper lobe	2	3	573·6	3848·56
6	64	M	AC	Right hilus	4	2	324·5	3409·7
7	57	M	SCC	Right lower lobe	4	2	521·3	4412
8	70	M	AC	Left upper lobe	4	2	515·9	3390·9
9	76	M	AC	Right hilar	4	2	301	5194·2
10	64	M	AC	Right lower lobe	1c	2	284·7	4929·5
11	74	M	SCC	Left upper lobe	4	2	436·8	3374
12	70	F	SCC	Right upper lobe	2	2	265·6	1885·5
13	63	M	AC	Right upper lobe	4	1	786·5	4259·2
14	68	M	AC	Right hilar	4	2	857·2	3411·4
15	75	M	SCC	Left lowe lobe	2	3	710·8	5029

SCC: squamous cell carcinoma; AC: adenocarcinoma.

Table 2. Comparison of dosimetric parameters

PTV parameters	Hybrid	Tomotherapy	p
CI	0.72 ± 0.07	0.66 ± 0.11	0.078
HI	0.08 ± 0.02	0.06 ± 0.01	**0.003**
D_{mean} (Gy)	61.79 ± 0.41	61.23 ± 0.28	**<0.001**
D_{max} (Gy)	65.48 ± 0.55	64.76 ± 0.81	**0.021**
Integral dose	36.33 ± 20.05	36.54 ± 19.06	0.712
D_2 (Gy)	63.63 ± 0.62	62.49 ± 0.45	**<0.001**
D_{98} (Gy)	58.72 ± 0.74	58.89 ± 0.47	0.509
V_{95} (%)	99.62 ± 0.2	99.6 ± 0.29	0.860
V_{100} (%)	94.69 ± 0.45	95.49 ± 0.63	**0.002**
V_{105} (%)	13.33 ± 11.94	0.69 ± 0.76	**0.001**
MU	373.4 ± 61.13	5884.07 ± 1851	**<0.001**
Beam on time (sc)	117.13 ± 27.11	412.21 ± 126.45	**<0.001**

The bold values' significance level is $p = 0.05$.

evidence-based data, it seems that the most relevant heart dose constraints are $V_{30} < 50\%$ and V45 < 35%.[17] Speirs et al. found heart V_{50} dose to be the strongest predictor (V_{50}: volume receiving ≥ 50 Gy). When stratified by heart V_{50} less than 25% versus 25% or greater, the 1-year overall survival (OS) rates were 70·2% versus 46·8%, and the 2-year OS rates were 45·9% versus 26·7%, respectively ($p < 0.0001$).[18] In our study, the doses given to the heart were below the limits in both techniques. D_{mean} and V_{30} values were lower in the hybrid plan. In the dosimetric study of Xu et al., the mean heart D_{mean} was found to be 18·2 Gy in HT, 12·7 Gy in VMAT and 12·5 Gy in IMRT in patients with PTV ≥ 312 cc ($p = 0.04$ for HT versus IMRT).[16] In our study, D_{mean} was found to be 14·5 Gy in the hybrid plan and 18·7 Gy in HT ($p < 0.001$).

Spinal cord D_{max} doses are generally tried to be kept ≤50 Gy. It can be difficult to provide these doses with 3DCRT. This problem can be overcome when 3DCRT and VMAT are combined.[19] In our study, spinal cord D_{max} was found to be suitable in both the hybrid plan and the tomo plan.

Radiation oesophagitis (RE) is an acute and chronic toxicity that significantly impairs quality of life and increases even more when RT is applied simultaneously with chemotherapy. Various DVH parameters are used to predict RE. Mean oesophageal dose (MED), maximal oesophageal dose, V_{20}, V_{35} and V_{60} are some of them.[20] In a metanalysis, V_{60} emerged as the best predictor for both moderate and severe RE. Three groups were determined according to V_{60} doses: low risk ($V_{60} < 0.07\%$), intermediate risk

Table 3. Comparison of OAR's dose volume parameters

	Hybrid	Tomotherapy	p
Total lung			
D_{mean} (Gy)	17.14 ± 4.59	17.25 ± 3.67	0.771
V_5 (%)	58.38 ± 18.21	63.63 ± 10.65	0.131
V_{10} (%)	42.85 ± 17.85	48.67 ± 10.49	**0.037**
V_{20} (%)	30.14 ± 10.73	30.27 ± 9.22	0.926
V_{30} (%)	23.23 ± 6.12	21.36 ± 6.7	0.101
Ipsilateral lung			
D_{mean} (Gy)	27.85 ± 5.01	25.53 ± 4.57	**0.005**
V_5 (%)	75.28 ± 13.04	75.83 ± 12.28	0.513
V_{10} (%)	66.64 ± 13.52	65.54 ± 10.63	0.488
V_{20} (%)	53.84 ± 11.33	49.38 ± 10.29	**0.029**
V_{30} (%)	44.04 ± 10.18	37.02 ± 7.95	**0.004**
Kontralateral lung			
D_{mean} (Gy)	7.78 ± 6.34	9.86 ± 5.09	**0.004**
V_5 (%)	43.37 ± 24.99	52.49 ± 18.35	0.170
V_{10} (%)	21.92 ± 24.82	33.03 ± 16.9	**0.020**
V_{20} (%)	9.34 ± 14.76	14.45 ± 11.96	**0.019**
V_{30} (%)	5.17 ± 8.59	7.5 ± 8.4	**0.028**
Heart			
D_{mean} (Gy)	14.55 ± 7.22	18.75 ± 7.7	**<0.001**
V_{30} (%)	18.14 ± 10.21	22.97 ± 11.79	**0.009**
V_{40} (%)	14.37 ± 8.49	16.62 ± 9.92	0.127
V_{60} (%)	4.87 ± 5.04	5.43 ± 5.39	0.145
Spinal cord			
D_{max} (Gy)	42.28 ± 7.52	41.49 ± 1.98	0.680
Oesophagus			
D_{max} (Gy)	61.05 ± 5.81	61.66 ± 3.85	0.666
D_{mean} (Gy)	23.16 ± 8.56	27.67 ± 8.46	**<0.001**
V_{35} (%)	33.76 ± 14.26	40.68 ± 15.42	**<0.001**
V_{40} (%)	31.06 ± 13.82	37.62 ± 15.58	**<0.001**
V_{60} (%)	10.44 ± 9.85	17.65 ± 12.73	**0.002**

The bold values' significance level is $p = 0.05$.

(V_{60} between 0·07% and 16·99%) and high risk ($V_{60} \geq 17\%$) risk.[21] While the mean oesophagus dose was achieved as ≤34 Gy in both techniques, V_{60} dose was found to be 17·6% in tomotherapy. D_{mean}, V_{35}, V_{40} and V_{60} doses were found to be lower in the hybrid plan.

The main limitation of this study was the variety of tumour size and localisation. This could be eliminated by initiating a long-term project with a higher number of patients included.

Conclusion

Suitable dose coverage and OAR doses can be provided with both techniques. Especially the opposite lung, heart and oesophagus doses can be kept lower with the hybrid plan, and lower MU and shorter beam on time can be provided.

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