VMAT, IMRT, versus 3D conformal radiotherapy techniques for locally advanced non-small-cell lung cancer irradiation

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Abstract:

Background: To compare the dosimetric difference between volumetric-modulated arc therapy (VMAT), intensity-modulated radiotherapy (IMRT), and 3D conformal radiotherapy (3D-CRT) using 6MV for locally advanced lung cancer patients.

Methods: A total of 30 treatment plans were calculated retrospectively for ten patients with advanced NSCLC using XIO planning system for 3D-CRT and Monaco Software (Version Monaco Medical Systems Inc., Version 5.11.2.) for IMRT and VMAT. For each case, three different delivery plans (3D conformal radiotherapy 6MV, IMRT, and VMAT) were done. We analyzed the heterogeneity index (HI) and conformality index (CI) of the planning target volume (PTV) and organs at risk (OARs) sparing.

Results: The coverage of PTV V95 was significantly better in the VMAT plan than the other two plans. The ipsilateral lung mean dose and its subvolumes showed higher doses in the conformal plan than the VMAT and IMRT plans but with no statistically significant difference.

The contralateral lung doses were higher in the VMAT plan and no statistically significant difference between the IMRT and conformal radiotherapy plans.

Conclusions: For locally advanced lung cancer patients, VMAT resulted in better PTV coverage than IMRT but with no statistically significant difference and both better than conformal radiotherapy with a statistically significant difference. However, the use of VMAT showed improvements in HI of the target and comparable OAR's sparing with a statistically significant but it showed an increase in V5 and V10 to both lungs, and all the contralateral lung parameters (mean dose, V5, V10, V20, and V30).

Keywords: dosimetric comparison; 3D conformal radiotherapy; intensity-modulated radiotherapy; volumetric-modulated arc therapy.

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Background:

Lung cancer is the leading cause of cancer death worldwide, representing 18 % of all cancer fatalities [1].

About 90% of lung cancers are non-small cell lung cancer (NSCLC). Concomitant chemoradiotherapy is the treatment approach for irresectable locally advanced non-small-cell lung cancer [2]. Radiotherapy treatment is a major challenge to deliver higher doses to the tumor volume with sparing of organs at risk (OARs). The use of modern techniques in radiotherapy helps to improve treatment efficiency. With CRT, about 4 to 6 fields are ported to PTV to deliver the prescribed dose to the tumor, sometimes used field in the field to improve the dose conformity around the target depending on physicist experience. In IMRT, we generally use about 6 to 12 static fields. The number of the segment in each field and weight distribution among fields depend on the algorithm of treatment planning. VMAT technique delivers the dose to target by rotating the gantry around the patient by one or more full or partial arcs. VMAT help in reducing the delivery time of treatment [3]. The aim of this study is to present the advantage of VMAT or IMRT rather than the 3DCRT for locally advanced non-small-cell lung cancer irradiation. This is by using statistical dosimetric comparisons among its.

Methods:

Patient characteristics

A total of 10 patients received radical radiotherapy for locally advanced NSCLC. All patients underwent pretreatment evaluations, including complete physical examination, Karnofsky performance status (KPS) scoring, hematological & biochemical panels, chest computed tomography, and PET CT. No patients had distant metastases.

Treatment planning

We performed three plans for each patient, 3D-CRT, IMRT, and VMAT techniques, with the dose of 60Gy in 30 fractions.

- Beams arrangement

3D-CRT (6MV)

3D-CRT, four to five fields were used in XIO (CMS) planning system. All fields were positioned at the iso-center of the tumor. Each plan used an open and wedged field. The selection of wedges and weights for each beam related to the uniformity of target dose coverage and sparing the risk structure.

IMRT

Designed on Monaco with 6 MV photon beams, nine beams were used with 40-degree increments started from 20-degree (20, 60, 100, 140, 180, 220, 260, 300, 340). The plans were optimized by inverse planning software for optimal PTV coverage and OAR sparing.

VMAT

VMAT plan used two dynamic arcs, each with 360° rotations (one from 181°-179° and the other from 179°-181°). The rotational arcs are automatically added and ported by the treatment planning system.

- Dose prescription

The gross target volume (GTV) and clinical target volume (CTV) were delineated according to PET CT results. The CTV to PTV margin was 5 mm

The prescribed dose 6000 cGy/30 fx (200 cGy/Fx). The spinal cord, both lungs, heart, esophagus were contoured as OARs.

- Plan evaluations

Dosimetric outcomes of 3D 6MV, IMRT, and VMAT included PTV and OAR coverage. Target volume coverage, dose homogeneity, and conformality index were assessed based upon ICRU83.

The quality of plans can be evaluated using the homogeneity index (HI) and conformality index (CI). The HI can be calculated by using the following equation:

$$HI = [D_2\text{-}D_{98}] / D_{50}$$

Where D_2 near-maximum dose, D_{98} near-minimum dose, and D_{50} is the median dose to target volume. The ideal value of HI is zero; the lower HI, the better the radiation distribution. The conformality index can be calculated as:

$$CI = V_{RI} / TV$$

CI =1 is an ideal value, and it presents the relation between the volume, which cover by reference dose ($V_{95\%}$) dividing by the total volume (TV) of the target. The RTOG radiation therapy organization group defines the volume of conformality to describe the quality of target conformation. If the value of CI is present between 1 to 2, the plan agrees with the treatment plan. If the value of CI lies between 2 to 2.5 or from 0.9 to 1, it is compatible with the treatment plan with a minor violation. When CI is more than 2.5 or less than 0.9, it is considered major but probably may be accepted [4,5]. Dmax, Dmin, and Dmean to PTV and percentage of PTV covered by ≥95% of the prescribed dose (V95%) were also used.

Organs at risk (OARs): Dmax, Dmean, and a series of RTOG-recommended values of OARs, including the spinal cord, heart, lungs, esophagus, were analyzed for each patient, with a lower value indicating better protection.

Statistical method

The Statistical Package of Social Science (SPSS) (version 26) was used to generate results. The normality of the data was tested using the Shapiro-Wilk single sample test. Data were presented as mean ± standard deviation or median (range). Friedman test was used to compare three groups.

Wilcoxon Signed Ranks Test was used to compare two groups; ($p \leq 0.05$) was considered significant.

Results:

The dosimetric comparison was made between 3 plans VMAT, IMRT, and 6MV 3D conformal radiotherapy for each patient (total 30 plans) receiving local treatment. The mean PTV volume was 496.7 cc ±175.0.

PTV dose coverage and conformality index

The PTV dose coverage of the three plans was evaluated by PTV minimum, maximum, and mean dose, PTV 100%,98%, 95%, 50 %, and the PTV maximum dose as shown in table 1, and figure 1 shows the difference in PTV coverage of the three plans.

We compared the three plans regarding the homogeneity and the conformality index as shown in table1, Figure2.

Organs at risk doses

Table 2 summarizes the DVH parameters of the organs at risk for the three plans regarding the Heart volume receiving 30 and 40 Gy, the spinal cord maximum dose, and esophagus mean dose, as well as different parameters for the ipsilateral and the contralateral lung subvolumes.

Figure 2 shows the difference in the ipsilateral mean lung dose and its subvolumes between the three plans.

Treatment Delivery Time and monitor units (MUs) in VMAT and IMRT plans

Table 3 shows the difference in the treatment delivery time and the monitor units received between the VMAT and the IMRT plan.

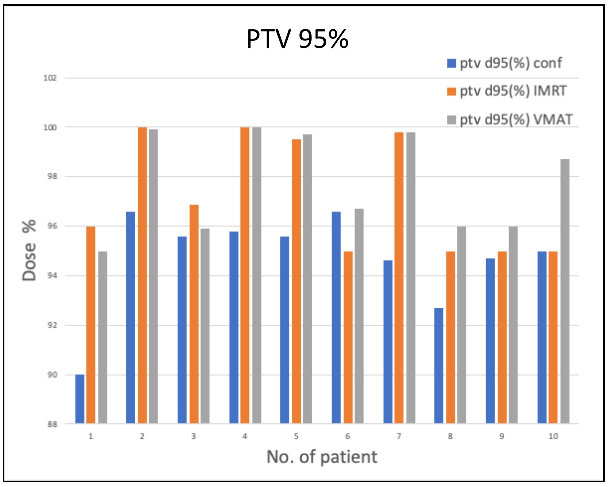

Figure 1: PTV coverage in the three plans

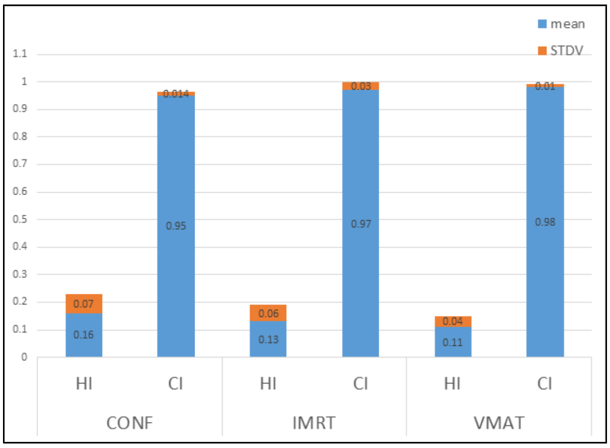

Figure 2: Homogeneity index and conformality index for ten patients using 3D Conformal, IMRT, and VMAT plans

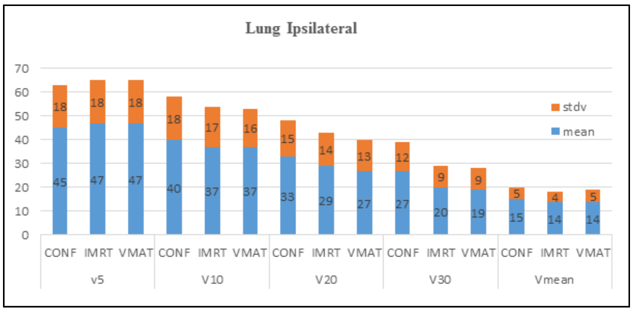

Figure 3: The ipsilateral lung doses for ten patients using 3D Conformal, IMRT vs. VMAT plans

Table 1: PTV dose coverage and homogeneity and conformality index.

Characteristics	Conformal	IMRT	VMAT	P-Value			
	Mean ± SD	Mean ± SD	Mean ± SD	All groups	Conformal IMRT	Conformal/ VMAT	IMRT/ VMAT
PTV dmin (Gy)	40.5±11.9	45.8±9.0	44.1 ± 11.6	0.003	0.011	0.221	0.791
PTV d max (Gy)	64.4±1.1	67.9±1.7	67.9±1.5	0.003	0.057	0.008	1.000
PTV mean (Gy)	59.9±0.9	62.0±0.3	61.6±1.0	0.002	0.005	0.076	1.000
PTV d100 %	66.8±9.9	91.3±6.3	84.9±15.9	0.002	0.002	0.172	0.353
PTV d 98% (Gy)	53.3±4.4	56.9±3.2	57.6±1.9	0.001	0.030	0.002	1.000
PTV d 95%	94.2± 3.3	97.2±2.3	97.8±2.0	0.002	0.042	0.004	1.000
PTV d 50% (Gy)	60.7±0.6	62.3±0.8	61.6±0.9	0.015	0.016	1.0000	0.172
PTV d 2% (Gy)	63.5±1.1	65.2±1.0	64.5±1.6	0.023	0.022	0.943	0.281
HI	0.168±0.0.07	0.134±0.06	0.111±0.04	0.057			
CI	0.952±0.01	0.975±0.02	0.981±0.01	0.002	0.057	0.002	0.943

Table 2: Organs at risk

Characteristics	Conformal	IMRT	VMAT	P-Value			
	Mean ± SD	Mean ± SD	Mean ± SD	All groups	Conformal IMRT	Conformal /VMAT	IMRT/VMAT
Heart V30 (%)	4.5±13.7	3.2± 7.1	3.6±9.0	0.936			
Heart V40 (%)	2.1±6.3	1.5 ± 4.4	2.2±6.1	0.264			
Spinal D max (Gy)	32.7± 11.1	39.8±3.4	38.9±5.4	0.061			
Both lungs V5 (%)	34.7± 16.3	43.6±15.8	45.2±16.5	0.004	0.101	0.004	0.791
Both lungs V10 (%)	27.1±12.7	30.7±13.2	33.7± 12.8	0.003	0.593	0.002	0.133
Both lungs V20 (%)	16.9±8.2	15.7±7.2	16.4±6.3	0.497			
Both lungs V30 (%)	13.2± 5.8	9.5±4.2	9.5±3.8	0.527			
Both lungs mean dose (%)	8.7±3.4	9.7±3.1	9.8±3.3	0.301			
Ipsilateral lung mean dose (%)	15.5±5.8	14.4±4.9	14.1±5.1	0.670			
Ipsilateral lung V5 (%)	45.7± 18.9	45.9±18.5	46.9± 18.4	0.670			
Ipsilateral lung V10 (%)	40.9± 17.9	37.9±17.5	37.9± 16.9	0.975			
Ipsilateral lung V20 (%)	33.6± 15.3	29.3±14.9	27.1±13.5	0.273			
Ipsilateral lung V30 (%)	27.1±12.6	20.6± 9.4	19.5±9.0	0.150			
Contralateral lung mean dose (%)	3.7±2.9	6.0±2.1	6.9±2.4	0.002	0.221	0.001	0.221
Contralateral lung V5 (%)	25.9±19.2	41.9±15.2	43.8±18.5	0.021	0.101	0.030	1.000
Contralateral lung V10 (%)	16.3±14.0	25.0±10.6	29.3±10.1	0.027	0.539	0.022	0.539
Contralateral lung V20 (%)	3.0±6.0	4.4±2.2	6.8±4.2	0.020	0.133	0.022	1.000
Contralateral lung V30 (%)	1.0±2.1	0.4±1.4	1.7±2.0	0.003	1.000	0.008	0.057
Esophagus mean dose (Gy)	16.4±8.2	20.6±7.7	21.1±9.6	0.074			

Table 3: Treatment Delivery Time and monitor units (MUs) in VMAT and IMRT plans

	VMAT	IMRT	P-value
MUs	1007.4 ± 218.8	892.8 ± 422.4	0.285
Treatment Delivery Time (min)	4.2 ± 1.6	8.4 ± 2.5	0.008

Discussion:

The aim of this work was to compare the dosimetric difference between VMAT and IMRT plans versus 3D-CRT plan in NSCLC patients.

The PTV coverage (dose 98 % and 95% volume) was better in the VMAT and IMRT than the conformal plan with a statistically significant difference, but there was no statistically significant difference between VMAT and IMRT despite higher PTV coverage in the VMAT plan.

The PTV to 100% volume was better in the IMRT plan than the VMAT plan with no statistically significant difference and better than the conformal radiotherapy plan with a statistically significant difference.

The maximum dose (d2%) was higher in the IMRT plan than the other two plans, with a statistically significant difference with the conformal plan.

There was no statistically significant difference between the three plans regarding the homogeneity index, with a better result in the VMAT plan than the other two plans.

The conformality index was better in the VMAT plan than the other two plans, with a statistically significant difference with the conformal plan.

Due to the difference in tumor location, there is a great variation in the heart dose with a greater dose to the heart in the conformal plan than the other two plans but with no statistically significant difference.

Also, for the spinal cord and esophagus dose, there was no statistically significant difference between the three3 plans, and all are within the tolerance dose.

There is strong evidence that radiation pneumonitis contributes to lung cancer patient death. In research including 1225 lung cancer patients who had concurrent chemoradiotherapy (CCRT), it was discovered that fatalities following treatment were related to radiation pneumonitis or pulmonary fibrosis [6].

In our study, the ipsilateral lung mean dose and its subvolumes showed higher doses in the conformal plan than the VMAT and IMRT plans but with no statistically significant difference.

The contralateral lung doses were higher in the VMAT plan and no statistically significant difference between the IMRT and conformal radiotherapy plans.

Several studies showed that VMAT reduces the delivery time and MUs compared to IMRT [7-10]. This was the same in our study as VMAT reduced treatment time compared to IMRT with a statistically significant difference, and this result in a decrease in the intrafraction patient motion, which can lead to target underdose and increased dose to OARs than calculated.

The comparison between 3D-CRT and VMAT was investigated widely [11,12]; they found that VMAT reduces the ipsilateral mean lung dose and improves PTV coverage and conformality.

Further studies are needed to correlate the impact of these techniques with early and late radiotherapy toxicity & if there is an impact on the outcome.

Conclusion:

For locally advanced lung cancer irradiation, VMAT resulted in better PTV coverage than IMRT but with no statistically significant difference and both better than conformal radiotherapy with a statistically significant difference. However, the use of VMAT showed improvements in HI of the target and comparable OAR's sparing with a statistically significant increase in V5 and V10 to both lungs, contralateral lung mean dose, V5, V10, V20, V30

List of abbreviations

3D-CRT	3D-Conformal Radiotherapy
CCRT	concurrent chemoradiotherapy
CI	conformality index
CTV	clinical target volume
GTV	gross tumor volume
HI	heterogeneity index
IMRT	Intensity-Modulated Radiation Therapy
KPS	Karnofsky performance status
MUs	monitor units
NSCLC	Non-small cell lung cancer
OARs	organs at risk
PTV	planning target volume
VMAT	Volumetric Modulated Arc Therapy
V5	Volume receiving 5 Gy
V10	Volume receiving 10 Gy
V20	Volume receiving 20 Gy
V30	Volume receiving 30 Gy

Conflict of interest

The authors declare no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

Authors' contribution

All authors actively contributed to the research and read and approved the final manuscript.

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