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RESEARCH ARTICLE

COMPARISON OF HYBRID TECHNIQUES WITH 3D-CONFORMAL RADIOTHERAPY IN PATIENTS WITH LUNG CANCER

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ABSTRACT

Purpose: It's postulated that hybrid techniques (HT) with lower weighting of IMRT/VMAT component would improve lung dose-volume parameters despite some disadvantage in PTV homogeneity index (HI) and target coverage (TC).

Material and Methods: Conformal plans were prepared using 6-10-15 MV-X photon energies while IMRT/VMAT plans of HTs were prepared using 6MV-X. Four HTs were developed having two different ratios (10% and 50%) of IMRT/VMAT component (h-IMRT1, h-IMRT2 and h-VMAT1, h-VMAT2, respectively). HTs were compared with 3D-CRT in terms of HI and TC for PTV, and total lung (TL) and contralateral lung (CL) $V_{5Gy,}$ V_{10Gy}, V_{20Gy} and mean lung dose (MLD).

Results: All HTs were advantageous for HI and TC, while disadvantageous for TL and CL-$V_{5Gy.}$ H-IMRT2 provided better TC than h-IMRT1, and so did h-VMAT2 compared to h-VMAT1. Lower weighting of IMRT/VMAT decreased TL and CL-V_{5Gy} in HTs. In addition, h-IMRT1 decreased TL and CL-MLD and CL-V_{20Gy} compared to h-IMRT2, while h-VMAT2 decreased TL-V_{20Gy} and CL-MLD compared to h-VMAT2.

Conclusion: In the RT of lung tumors close to vertebra, it may be appropriate to suggest a ratio of IMRT/VMAT component approximately 10% in order to decrease the low and intermediate dose-wash lung volume, if HI and TC values are acceptable.

Keywords: hybrid technique, intensity modulated radiation therapy, lung cancer, radiotherapy, treatment planning, volumetric modulated arc therapy.

INTRODUCTION

Radiotherapy (RT) is an essential treatment modality in the treatment of lung cancer. It is crucial that tolerance dose limits should not be exceeded in lungs, heart, esophagus, and especially in the spinal cord (SC) while performing RT to lung tumors. However, the biggest challenge in the RT of lung cancer is to give the desired dose to the planning target volume (PTV) while minimizing the volume of lungs exposed to low and medium doses to prevent radiation pneumonitis. This is due to the presence of tissues with different densities within thorax, and the variation of body thickness through thorax.

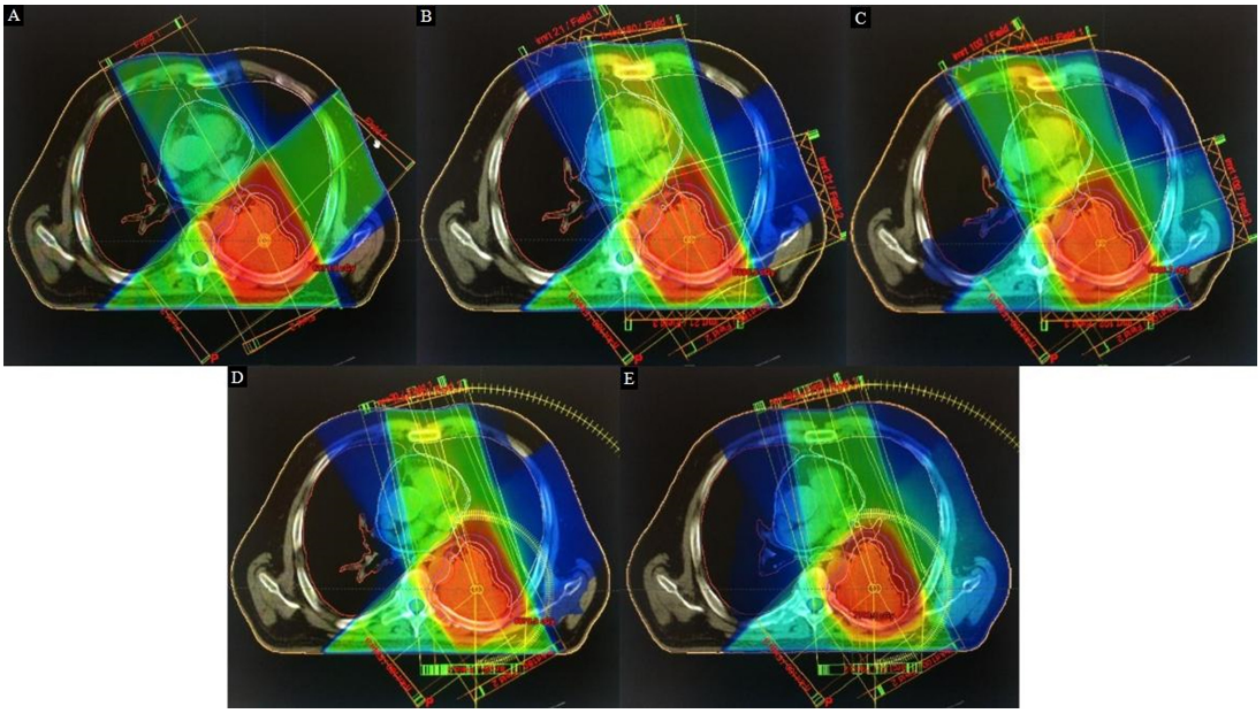

Figure 1. Color wash dose distribution (>500 cGy) of five techniques shows that higher weighting of IMRT/VMAT component causes larger low dose volumes. (A) 3D-CRT (B) h-IMRT1, (C) h-IMRT2, (D) h-VMAT1, (E) h-VMAT2

Advanced RT techniques such as Intensity Modulated RT (IMRT) and Volumetric Modulated Arc Therapy (VMAT) enable us to administer the prescribed doses to the PTV with minimum dose to organs at risk (OAR). However, these techniques might expose larger lung volumes to low doses compared to 3-dimensional conformal RT (3D-CRT). Hybrid techniques (combination of 3D-CRT and IMRT/VMAT) (HTs) have been proposed to balance the inadequate conformity of 3D-CRT and extensive low dose OAR volumes in IMRT/VMAT (1, 2). However, the optimal percentage of IMRT/VMAT component in HTs is not clear.

Patients having lung tumors invading or adjacent to vertebra constitute a subgroup for whom it is hard to give the desired dose to PTV without exceeding SC and lung tolerance dose. In this context, in our study performed in patients with lung tumors close to vertebra, we postulated that: 1) HTs would improve PTV dose homogeneity and target coverage (TC) compared to 3D-CRT 2) HTs with lower weighting (10%) of IMRT/VMAT component would improve lung DVH parameters while displaying some disadvantage in PTV dose homogeneity and TC compared to HTs with higher weighting (50%) of IMRT/VMAT component.

MATERIAL AND METHODS

In this study, CT-simulator data of eight consecutive patients with lung cancer close to vertebrae (adjacent to or invading vertebra) who received RT were used retrospectively. The approval for this study was given by Dokuz Eylul University Ethics Committee for Non-invasive Research (No: 2014/36-03, Date: 14.12.2014). The reason of not taking written informed consent was the lack of cooperation of patients or their relatives in mailing back the consent forms. The target volumes of the cases were re-drawn by a radiation oncology resident, checked by a radiation oncology attending, and necessary corrections were made. Then, virtual treatment plans were created independent of the previously applied beam configuration, dose and fractionation. By analyzing new data obtained from the generated plans, the results were evaluated.

The Treatment Planning System (TPS) used was able to process the data of Varian “TrueBeam STx" linear accelerator. CT images of the cases were acquired by Siemens Emotion X-ray CT-simulator device. These images were transferred to the Eclipse TPS (Version 11) for planning.

Virtual treatment plans were created for each patient by using five different techniques (3D-CRT, h-IMRT1, h-IMRT2, h-VMAT1, and h-VMAT2). Regardless of

Table 1. Mean values of PTV HI and TC for five different techniques

	PTV	
	HI Mean±SE (range)	**TC Mean±SE (range)**
3D-CRT	1.08±0.01 (1.06-1.12)	0.54±0.01 (0.48-0.58)
h-IMRT1	1.05±0.004 (1.04-1.07)	0.62±0.02 (0.52-0.72)
h-IMRT2	1.05±0.002 (1.04-1.06)	0.77±0.04 (0.67-0.98)
h-VMAT1	1.04±0.002 (1.04-1.05)	0.82±0.04 (0.62-0.93)
h-VMAT2	1.04±0.002 (1.03-1.05)	0.95±0.02 (0.86-0.99)

SE: Standard Error

Table 2. Results of comparison of five different techniques in terms of HI and TC

	PTV p Values	
Comparison Type	**HI**	**TC**
3D-CRT/h-IMRT1/h-IMRT2/h-VMAT1/ h-VMAT2	**<0,001**	**<0,001**
3D-CRT/h-IMRT1	**0,01**	**0,01**
3D-CRT/h-IMRT2	**0,01**	**0,01**
3D-CRT/h-VMAT1	**0,01**	**0,01**
3D-CRT/h-VMAT2	**0,01**	**0,01**
h-IMRT1/ h-IMRT2	0,09	**0,01**
h-VMAT1/ h-VMAT2	0,02	**0,01**

the previously applied dose fractionation schedules, the virtual treatment plans used a fraction dose of 200 cGy up to a total dose of 4800-6600 cGy, depending especially on the SC tolerance dose.

In treatment planning, beam directions and energies depended on the location and size of the PTV, as well as the thickness and anatomy of the patient. In 3D-CRT planning, four fields were used: 2 from front and 2 from backward directions with 6, 10, 15 MVX energies as needed, as shown in Figure 1a. In the conformal component of hybrid plans, three fields were preferred: 1 from front and 2 from backward directions with 6, 10, 15 MV X energies as needed. Multi-leaf collimator (MLC) leaves were automatically shaped by giving a 7 mm safety margin around PTV for the fields formed in 3D-CRT and conformal component of HT. According to the position of target volume, the safety margin was slightly reduced on the SC side in order not to exceed its tolerance dose. Virtual wedges with appropriate angles were implemented in the fields to obtain a homogeneous dose distribution in PTV. Two conformal plans of the same standard were created that form the 90% and 50% of the 200 cGy fraction dose. These conformal plans were used as base plans in order to generate the IMRT and VMAT components.

The percentage of IMRT/VMAT component was determined as 10% and 50%, representing relatively low and high percentages, respectively. While planning IMRT component of the h-IMRT technique, three fields were used: 2 from the front and 1 from the backward directions with beam angles different from the ones in the conformal component. In all radiation fields, 6 MV X beam energy was chosen and based on conformal plans supplying 90% and 50% of the fraction dose; IMRT plans were created by supplying the remaining 10% (h-IMRT1) and 50% (h-IMRT2) of the fraction dose, respectively. Optimization was performed based on the conformal components. In the planning of VMAT component of the h-VMAT technique, 2 partial arcs of 194° were formed with 6 MV X beam energy to protect contralateral lung (CL). As in h-IMRT technique, VMAT plans were created supplying the remaining 10% (h-VMAT1) and 50% (h-VMAT2) of the fraction dose, respectively. Optimization was performed using the same conformal components used as base plans in h-IMRT techniques.

"Analytical Anisotropic Algorithm" (AAA) was used for dose calculation in all techniques. In addition, the dose was prescribed to the 100% isodose line and $D_{95\%}$ was required to be at least 93% in all treatment plans for all patients. During optimization, dose constraints to OARs (esophagus, lungs, SC and heart) were considered.

As stated in the literature for lung (1-4), V_{5Gy}, V_{10Gy}, V_{20Gy} and Mean Lung Dose (MLD) were recorded from dose-volume histograms (DVHs). In addition, the parameters ($D_{5\%}$, $D_{95\%}$, TV_{PIV}, TV) required for the calculation of Homogeneity Index (HI) and TC regarding PTV (5, 6) were recorded using DVHs.

$HI = D_{5\%}/D_{95\%}$

($D_{5\%}$: dose received by 5% of the PTV, and $D_{95\%}$ = dose received by 95% of the PTV)

$TC=TV_{PIV}/TV$

(TV_{PIV}: PTV volume receiving the prescribed dose, TV: total PTV volume, PIV: volume receiving the prescribed dose)

Table 3. Mean values of total lung dose-volume parameters for five different techniques

	Total Lung			
	V_{5Gy} (%) Mean±SE (range)	V_{10Gy} (%) Mean±SE (range)	V_{20Gy} (%) Mean±SE (range)	MLD (Gy) Mean±SE (range)
3D-CRT	27.9±4.5 (10.9-46.9)	22.7±3.8 (8.7-38.6)	17.8±3.1 (6.4-31.3)	864±145 (287-1425)
h-IMRT1	30.3±5.1 (11.2-53.1)	23.8±4.3 (8.7-41.8)	15.1±3 (3.5-27.4)	865±150 (273-1453)
h-IMRT2	32.9±5.7 (13.1-60.8)	24.4±4.4 (8.7-42.7)	17.1±3.5 (4.3-31.3)	901±156 (306-1527)
h-VMAT1	31.7±5.1 (11.7-54.2)	24.3±4.3 (8.8-42.2)	15.1±2.9 (3.4-26.5)	884±147 (290-1462)
h-VMAT2	39.2±5.6 (16.1-63.2)	25.1±4.1 (8.8-41.6)	16.1±3.1 (3.9-27.5)	918±145 (330-1503)

SE: Standard Error

Analysis of the data was performed using SPSS Version 15.0. Friedman test was used to compare five related data (5 different treatment techniques). Wilcoxon Signed Rank test was used to compare two related data (comparisons of 3D-CRT with each of four HTs, and h-IMRT1 vs h-IMRT2, and h-VMAT1 vs h-VMAT2 comparisons).

For statistical significance, p<0,05 was required in the Friedman test, whereas p<0,01 in Wilcoxon Signed Rank test (Bonferroni correction was performed due to the presence of 6 comparisons of two-related data.).

RESULTS

Eight patients in the study were applied 5 different RT techniques, independent from their actual dose-fractionation and RT techniques. Median total dose was 5475 cGy (range, 4800-6600 cGy) while fraction dose was 200 cGy.

PTV

Mean PTV $D_{95\%}$ provided by any technique was 98.3% (93.0%-102.2%) in all cases. Mean HI and TC values and results of comparison of five different techniques in terms of HI and TC are shown in Table 1 and Table 2, respectively. Significant differences were found in terms of HI and TC in the comparison of five different techniques as well as all the paired comparisons of HTs with 3D-CRT technique (p=0.01). In addition, significant differences were found in terms of TC in the comparison of h-IMRT1 vs h-IMRT2 as well as h-VMAT1 vs h-VMAT2 (p=0.01). According to results in Table 1, h-VMAT techniques appear to show relatively better TC with respect to h-IMRT techniques.

Lung

In Figure 1, color wash dose distribution (>500 cGy) of five different techniques are showed. Mean values and results of comparison of five different techniques in terms of total lung (TL) dose-volume parameters are shown in Table 3 and Table 4, respectively. When all five techniques were compared regarding lung parameters, significant difference was observed for V_{5Gy}, V_{10Gy}, V_{20Gy} and MLD (p<0.05). 3D-CRT technique was detected to provide the lowest V_{5Gy} compared to others. In the paired comparison of all HTs with 3D-CRT technique, V_{5Gy} showed a significant difference (p=0.01), however, this difference was not detected for V_{10Gy} and V_{20Gy}. In addition, in terms of MLD, significant difference was only observed between h-VMAT2 and 3D-CRT technique (p=0.01).

H-IMRT1 decreased V_{5Gy} and MLD compared to h-IMRT2 (p=0.01). H-VMAT1 decreased V_{5Gy}, and V_{20Gy} compared to h-VMAT2 (p=0.01).

As for the mean V_{5Gy} of the lung, h-VMAT techniques gave relatively higher values than their equally weighted h-IMRT counterparts. H-VMAT2 technique seemed to provide relatively lower V_{20Gy} than h-IMRT2. It was observed that h-VMAT techniques caused relatively higher MLD values than h-IMRT techniques.

Mean values and results of comparison of five different techniques in terms of CL dose-volume parameters are shown in Table 5 and Table 6, respectively. When all 5 techniques were compared regarding CL parameters, significant difference was observed for V_{5Gy}, V_{10Gy}, V_{20Gy} and MLD. 3D-CRT technique yielded the lowest CL V_{5Gy} and MLD compared to others. Paired comparison of all HTs

Table 4. Results of comparison of five different techniques in terms of total lung dose-volume parameters

	Total Lung p Values			
Comparison Type	**V_{5Gy}**	**V_{10Gy}**	**V_{20Gy}**	**MLD**
3D-CRT/h-IMRT1/h-IMRT2/h-VMAT1/h-VMAT2	**<0,001**	**0,01**	**<0,01**	**<0,01**
3D-CRT/h-IMRT1	**0,01**	0,09	0,02	0,58
3D-CRT/h-IMRT2	**0,01**	0,03	0,55	0,05
3D-CRT/h-VMAT1	**0,01**	0,02	0,02	0,07
3D-CRT/h-VMAT2	**0,01**	0,02	0,07	**0,01**
h-IMRT1/ h-IMRT2	**0,01**	0,06	0,02	**0,01**
h-VMAT1/ h-VMAT2	**0,01**	0,13	**0,01**	0,02

with 3D-CRT technique revealed significant difference for CL V_{5Gy} (p=0.01), whereas no significant difference for CL V_{10Gy} and $V_{20Gy.}$ In addition, only h-IMRT2 and h-VMAT2 techniques showed significant differences compared to 3D-CRT technique in terms of CL MLD (p=0.01).

H-IMRT1 decreased CL V_{5Gy}, V_{20Gy} and MLD compared to h-IMRT2 (p=0.01). H-VMAT1 decreased CL $V_{5Gy,}$ and MLD compared to h-VMAT2 (p=0.01).

H-VMAT techniques revealed relatively higher CL V_{5Gy} than their equally weighted h-IMRT counterparts. H-VMAT2 technique seemed to provide relatively lower CL V_{20Gy} than h-IMRT2. H-VMAT techniques caused relatively higher CL MLD compared to h-IMRT techniques.

Table 5. Mean values of contralateral lung dose-volume parameters for five different techniques

	Contralateral Lung			
	V_{5Gy} (%) Mean±SE (range)	**V_{10Gy} (%) Mean±SE (range)**	**V_{20Gy} (%) Mean±SE (range)**	**MLD (cGy) Mean±SE (range)**
3D-CRT	9.3±1.8 (4.3-19.1)	6.1±1.1 (2.9-12.1)	3.8±0.9 (1.2-8.7)	254±47 (132-527)
h-IMRT1	12.4±2.5 (5.2-25.1)	7.4±1.7 (3.6-17.2)	3.5±0.8 (1.1-6.9)	297±47 (165-499)
h-IMRT2	17.7±3.7 (8-38.4)	9.1±1.8 (3.6-16.2)	5.5±1.3 (2.3-10.1)	389±70 (189-694)
h-VMAT1	14.2±2.7 (5.8-27.1)	7.5±1.7 (3.6-17.4)	3.5±0.8 (1.3-7)	337±46 (186-520)
h-VMAT2	28.9±4.5 (11.7-44.8)	8.7±1.5 (4-15.5)	2.8±0.6 (1.3-6)	423±51 (230-660)

DISCUSSION

Compared to IMRT or conformal techniques, VMAT decreases monitor unit (MU) values approximately by 50-60% (5, 7). As MU values decrease, the amount of scattered radiation also decreases, and so does the incidence of secondary malignancies. In addition, because of shortening of treatment duration, uncertainties originating from the organ motion are reduced. Moreover, RT devices can be used more efficiently due to the increase in daily patient turnover. However, when highly conformal techniques like IMRT or VMAT is used in the RT of moving tumors like lung cancer, so-called "motion interplay" effect may occur because of mismatch between motion of the MLC and motion of the tumor, where hot and cold spots occur in the PTV (8). This phenomenon can lead to the formation of radiation pneumonitis due to the increase in lung volume receiving low doses of radiation (2, 8). In a study examining the effect of “motion interplay” on the planned dose distribution, Schwarz et al. reported a dose change of 7% in GTV D_{min}. The potential of exceeding the OAR tolerance levels for SC and esophagus was also highlighted in that study (9). In addition, dosimetric uncertainties caused by the small fields created to provide homogeneous dose distribution in the target in IMRT or VMAT techniques might raise concerns in terms of reliability of the treatment plan.

In the four comparative planning studies on lung cancer available in the literature, which included HT at least in one study arm, weight of IMRT/VMAT component ranged between 10% and 50% due to

Table 6. Results of comparison of five different techniques in terms of contralateral lung dose-volume parameters

	Contralateral Lung p Values			
Comparison Type	**V_{5Gy} (%)**	**V_{10Gy} (%)**	**V_{20Gy} (%)**	**MLD**
3D-CRT/h-IMRT1/h-IMRT2/h-VMAT1/h-VMAT2	**<0,001**	**0,02**	**<0,01**	**<0,001**
3D-CRT/h-IMRT1	**0,01**	0,08	0,67	0,05
3D-CRT/h-IMRT2	**0,01**	0,02	0,06	**0,01**
3D-CRT/h-VMAT1	**0,01**	0,05	0,67	0,03
3D-CRT/h-VMAT2	**0,01**	0,02	0,45	**0,01**
h-IMRT1/ h-IMRT2	**0,01**	0,03	**0,01**	**0,01**
h-VMAT1/ h-VMAT2	**0,01**	0,21	0,06	**0,01**

differences in mean PTV volume in studies (1, 2, 10, 11).

In their study of 24 patients with lung cancer, Chan et al. have compared 3D-CRT, VMAT and h-VMAT techniques (10). They used 2 partial arcs of 204° in the VMAT plans. The ratio of conformal component was 50% in h-VMAT technique. Compared to 3D-CRT, VMAT and h-VMAT caused a significant increase of 20% in Conformity Index (CI). However, V_{5Gy} and V_{10Gy} increased significantly in VMAT technique with respect to 3D-CRT. These parameters in h-VMAT plans were similar to 3D-CRT. Significant decrease was observed in h-VMAT technique in that study in all lung dose-volume parameters (MLD, V_{5Gy}, V_{10Gy}, V_{20Gy}) compared to VMAT. The reason that MLD was lower in h-VMAT compared to 3D-CRT is that the preferred number of fields (5-7 fields) was relatively high in the 3D-CRT technique.

Mayo et al. have comparatively evaluated h-IMRT, 3D-CRT, 4-5 field IMRT and 9 field IMRT technique in 18 patients of which 12 had lung and 6 had esophageal cancer (1). In this study, 3D-CRT plans comprising 2-3 fields were taken as base plan, and optimization was achieved by creating the IMRT component with different beam angles from the ones in 3D-CRT fields. The ratio of the conformal component was 2/3 in the h-IMRT technique in that study. At low dose levels, improvement in TL protection was detected in h-IMRT with respect to IMRT. In h-IMRT technique, V_{5Gy} and V_{13Gy} of TL and CL were observed to be significantly lower than the 9 field IMRT plans. Compared to 4-5 field IMRT, h-IMRT significantly reduced V_{5Gy} of TL and CL as well as V_{20Gy} of CL (1).

In their study of 8 patients with lung cancer, Agapito et al. have compared h-VMAT with 3D-CRT (2). In that study, two partial arcs were used in most of the cases for creating VMAT component. Compared to 3D-CRT, h-VMAT showed significant decrease in only CL V_{10Gy} (p=0.015). Again, compared to 3D-CRT, h-VMAT technique provided significant decrease in MLD (p=0.001), V_{20Gy} (p=0.018) and V_{10Gy} (p=0.011) of TL, but not in V_{5Gy}. In addition, h-VMAT was significantly superior to 3D-CRT in terms of PTV conformity (p= 0.000) (2).

In their study of 14 patients with lung cancer, Verbakel et al. have compared five different techniques (3D-CRT, IMRT, VMAT, h-IMRT, h-VMAT). They used 3 fields in IMRT, one from front, one from backward and one lateral (270 °/90 °), and single partial arc of 209° in VMAT. In the HT, 89% of the dose was given using 3D-CRT. Mean V_{5Gy} of CL and mean V_{20Gy} of TL displayed the lowest values in h-IMRT and h-VMAT techniques. In addition, compared to 3D-CRT, both h-IMRT and h-VMAT plans were observed to succeed approximately 3% lower absolute values of TL V_{20Gy}. Moreover, both h-IMRT and h-VMAT were found to achieve 11% and 18% lower absolute values of CL V_{5Gy} than IMRT and 3D-CRT, respectively. The reason that the HTs achieved lower CL V_{5Gy} was simply because of the high number of fields (5-9 fields) selected in 3D-CRT in that study. In Verbakel et al.'s study, there was no difference between h-IMRT and h-VMAT techniques

regarding PTV coverage and protection of the lung tissue (11).

Because the weight of IMRT/VMAT component ranged between 10% and 50% in the present studies with HTs, the lowest (10%) and highest (50%) weight of IMRT/VMAT components were chosen for HTs in our study. All hybrid plans in our study created significantly more homogenous dose distribution and better TC for PTV compared to 3D-CRT. In our study, the most extensive increase in TC was observed in both h-VMAT techniques among four HTs. As postulated, TC was better for HTs with higher weighting of IMRT/VMAT component in our study.

In our study, 3D-CRT displayed the lowest values in TL and CL V_{5Gy} parameter in all paired comparisons. Similarly, Mayo et al. have reported lower mean TL V_{5Gy} in 3D-CRT than h-IMRT, although not significant (1). On the other hand, it is important to note that the number of fields selected in 3D-CRT in the studies obtaining similar or lower values with HTs (10, 11) for TL V_{5Gy} was significantly higher than that of Mayo et al.'s and our studies.

Although not significant, V_{10Gy} being similar in h-VMAT and 3D-CRT in the study of Chan et al. (10) was consistent with our results. Lower TL V_{10Gy} in h-VMAT compared to 3D-CRT in Agapito et al.'s study differs from our results. This might be because 3D-CRT beam angles in their study did not avoid CL, unlike in our study.

In other studies (2, 10, 11) as well, TL V_{20Gy} was lower in HTs than in 3D-CRT. These results are consistent with our study.

In addition, pairwise comparisons with 3D-CRT in our study revealed significantly higher TL MLD in h-VMAT2 and CL MLD in both h-IMRT2 and h-VMAT2. On the other hand, Chan and Agapito have found lower TL MLD in HT than in 3D-CRT (2, 10). This difference in the results is because of the limited number of fields and beam angles avoiding CL in 3D-CRT technique in our study.

Unlike other studies, we performed a comparison between HTs with different weighting of IMRT/VMAT component to determine the relevant weighting that improves lung dose-volume parameters. In our study, V_{5Gy} of TL and CL were detected higher in HTs with greater IMRT/VMAT component. This difference was even more prominent between h-VMAT techniques. In our study, H-IMRT1 also decreased MLD compared to h-IMRT2, and H-VMAT1 also decreased V_{20Gy} compared to h-VMAT2. Thus, we suggest the relevant weighting of IMRT/VMAT component that improves lung dose-volume parameters should be approximately 10%.

The limitation of our study is the small number of patients. It could be argued that the prescribed dose has a large range (4800-6600 cGy) in our study, which is because of the tumor's proximity to the SC. However, due to the use of Wilcoxon signed-rank test and Friedman test for comparisons (comparison of two and k-related samples, respectively), this issue does not influence the statistical accuracy of the study negatively. It should be noted that there is no study in the literature comparing two HTs using different ratios of IMRT/VMAT component, and our study is the first one ever focusing on this issue. Further studies are required on this topic.

CONCLUSION

In the RT of lung tumors close to vertebrae, adequate dose delivery to the target achieving high HI and TC values without exceeding tolerance dose limits may not be possible by 3D-CRT in some cases. In this study, we observed that all HTs used in such cases improved HI and TC compared to 3D-CRT.

The low and intermediate dose wash of lungs decrease with HTs using lower weighting of IMRT/VMAT component. Thus, it might be recommended to keep the IMRT/VMAT component at approximately 10% in HTs not to increase side effects to lung if the PTV HI and TC values are acceptable.

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Conflict of interests: None

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