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The role of Modulation Complexity Score (MCS) of the VMAT and IMRT techniques in the treatment planning of left non-small lung cancer

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ABSTRACT

Background: Lung cancer is a common disease for patients over the age of 50 years, especially males due to smoking habits. This study aimed to compare the modulation complexity score (MCS) for the advanced treatment planning techniques which the intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT).

Materials and Methods: Thirty patients who had non-small lung cancerous tumors on their left side participated in this study. The range ages were 68 to 98 years, the heights were between 151 and 182cm and they having weights from 46 to 79 kg. For Each patient will create two plans dial using two different techniques, which will be Intensity Modulated Radiation Therapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) in the Monaco 5.1 version, and then those plans will be forwarded to the Infinity Linear Accelerator (LINAC). For the purposes of evaluation, the dose volume histogram is utilized to perform the calculation necessary to determine the dose for tumors and Organs at Risk (OAR). After that, the modulation complexity score, also known as the MCS, was determined using the multiyear collimators of the plans.

Results: Showed that the mean age of males was (82.6 ± 4.93) years, while the mean age of females was (72.12 ± 3.13) years. The proportion of males was significantly higher than that of females. The female patient had a higher body mass index than the male patient. The mean height of men in this study was (172.85 ± 2.02) cm, while the mean height of women was (156.32± 1.21) cm. The coverage planning target volume (PTV) for the left lung tumor shows that the VMAT was significantly higher than the IMRT at 95%, 98%, 5%, and 2%. When comparing IMRT and VMAT for the PTV 105%, there was no discernible difference between the two. According to the statistics, the conformity and homogeneity of the dose delivered by the VMAT was noticeably higher than those delivered by the IMRT. According to the findings of the study, the MCS score for the VMAT is noticeably higher than that of the IMRT. In the case of the IMRT technique, the relationship between the MCS and the total number of monitor units was found to be positive and direct, whereas in the case of the VMAT technique, the relationship was found to be negative and inverse.

Conclusions: The volumetric modulated arc therapy (VMAT) shows a better coverage and less complexity technique and could protect the heart, spinal cord, and right lung than the IMRT.

Key words: VMAT, IMRT, HI, CI, MCS.

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INTRODUCTION

Managing non-small lung cancer cell (NSLCC) is one of radiotherapy's most challenging tasks. 3D-CRT is a potential treatment for NSLCC due to improved radiation portal shape and conformal avoidance of normal structures [1,2]. Intensity-modulated radiotherapy (IMRT) has significantly improved dose compatibility and organ-sparing compared to 3DCRT [3]. However, more MUs might increase the risk of secondary radiation-induced cancer [4,5], and the longer treatment time of IMRT might lead to more pain of patient, whereas Volumetric modulated arc therapy (VMAT) increase conformal target coverage and OAR sparing while reducing treatment delivery time and the number of necessary MUs [6–11]. VMAT is used to reduce side effects of 3DCRT such as acute radiation dermatitis, fatigue, pain within the irradiated area, sore throat, dysphagia, nausea and acute toxicity related to; Radiation dose, a combined used of chemotherapy with radiation therapy and surgery [12,13].

In general, the distribution of the absorbed dose within the target volume is described as dose homogeneities [14–16]. Depending on the radiotherapy modality used, different definitions of the homogeneity index have been established. A new definition of homogeneity index was proposed by the ICRU in 2010 in order to address issues with existing indexes, which consider only the minimum or maximum dose or the use of reference point doses [16]. It is recommended that homogeneity index is defined as follows:

$$HI = \frac{D2\% - D98\%}{D50\%}$$

D98% is the dosage absorbed in 98% of the isodose line, D50% is the dosage absorbed in 50% of the isodose line and D2% is the dosage absorbed in 2% of the isodose line. The absorbed-dose distribution is nearly homogeneous when the HI value is equal zero [16]. The degree to which a high dose zone, PTV, corresponds to the target volume is referred to as conformance to the dose delivered. Based on the isodose volume supplied by the treatment plan, the conformity index (CI) is used to assess the conformal coverage of the PTV [16, 17]:

$$CI = \frac{V_{PTV} \times V_{TV}}{TV^{2}_{PV}}$$

CI is the Conformity Index, VTV is the volume of the actual prescribed dose, VPTV is the volume of PTV and TVPV is the volume of VPTV within VTV. The treatment conformity is achieved when the optimum is at CI =1.

The MCS was first developed [18]. Beam complexity is measured by the number of possible MLC movements that could occur during beam delivery. Step-and-shoot IMRT was the initial application for which the MCS was designed. The relative weights of the beam segments are utilized to compute the beam's complexity score. The MCS to be compatible with sliding window IMRT [19], where the beam's complexity was defined by the relative relevance of the control points (CP). In step-and-shoot IMRT, the MCS takes into consideration information from the TPS, such as changes in the positons of the MLC-leaves, variations in beam shape, and the relative relevance of each segment's MU [18, 20].

Aperture Area Variability (AAV) determines the size of the beam aperture, while Leaf Sequence Variability (LSV) determines the variability in leaf positioning [19,21,22]. The MCS beam is the product of the LSV segment and the AAV segment weighted by their respective MUs. The MCS plan metric describes the total plan complexity. The MCS strategy is the beam's MCS multiplied by the relative MU of each beam. The score for each beam is based on a combination of three parameters derived directly from the treatment planning system: leaf position, segment form, area, and weight [22].

Previous studies on the MCS employed a variety of approaches. A gamma assessment of user-defined MLC-created patterns and AAPM TG 119 benchmark plans in order to evaluate the Octavius 4D system, and the association between plan complexity as defined by the MCS and the gamma index was examined utilizing a planar and volumetric gamma investigation of 106 clinically authorized VMAT patient plans from various regions [23]. The Octavius 4D system was found to be appropriate for patient-specific pretreatment quality assurance. The results of the global and local gamma analyses showed a tenuous relationship with the MCS.

Linking the MCS with organ location and estimating potential dosage errors for organs before beam delivery for IMRT dosimetry, where for all organs and volumes of interest, they found a weak correlation between dosage errors and the MCS edge, with the exception of the gross tumor volume, brain stem, and spinal cord. Also, the SEM showed a slight increase in sensitivity in other organs that was associated with dosage mistakes [24]. Grams M. et al., proposed an innovative and applicable VMAT planning technique with grid treatment. For example, two cases that were spherical mass within the GTV, 20 Gy was determined for treatment of 1703 cm^3 of mediastinum mass while for treatment of 3680 cm^3 of abdominal tumor, 18 Gy to 32 Gy within the GTV was determined. In addition, both patients received additional consolidative radiation therapy approximately one week after their initial VMAT grid therapy [25]. Without any treatment-related side effects, the tumors of each patient shrank significantly, and their symptoms improved. Some researchers described a method for planning VMAT grid therapy sessions that can be administered in a clinically feasible amount of time [26].

The current study will focus on the effect of the MCS of the VMAT and IMRT techniques in a left non-small lung cancer treatment plan. Therefore, the purpose of this study is to compare VAMT and IMRT techniques to determine which is superior for treating non-small lung cancer depending on MSC.

MATERIALS AND METHODS

This study was conducted on patients attending the Al-Imam Al-Sadeq Hospital and Al-Najaf Teaching Hospital in Iraq during the period from October 2022 to June 2023. Ethical approval was obtained from the University of Baghdad College of Medicine in cooperation with the Ministry of Health (Al-Imam Al-Sadeq Hospital and Al-Najaf Teaching Hospital). It was as part of the assessment of The Role of Modulation Complexity Score (MCS) of the VMAT and IMRT Techniques in the Planning of Left Lung Tumor.

Subjects

30 patients with non-small lung tumors represent the number of samples (male and female) involved in the current study. Male's percentage was 80% whereas female's percentage was 20%. The range ages were 72 to 98 years and from 68 to 77 years for males and females, respectively. The heights were between 168 and 182 cm for males and between 151 to 168 cm for females, as well as having weights from 46 to 75 kg for males and from 55 kg to 79 kg for females.

Inclusion criteria

The left lung cancer patients with chemotherapy met the inclusion criteria.

Exclusion criteria included lung tumors smaller than 2 centimeters, patients younger than 20 years of age, large peripheral tumors located far from the heart and spinal cord, and tumors invading other organs such as the heart or vertebrae.

Treatment Method

All patients with non-small left lung cancer were prepared for dynamic IMRT and VMAT treatment planning techniques using the MONACO 5.1 treatment planning system (TPS). Patients will be treated with an Elekta linac (Infinity) and a 6-MV X-ray photon beam (linear accelerator).

When test results indicate that a patient requires radiation therapy, the first decision an oncologist makes is to obtain a 3D image of the patient using a CT scan. For the CT simulation, we utilized a SIEMENS SOMATOM Confidence (syngo CT VB10A) with 64 slices, lying flat and facing headfirst. With the assistance of the MONACO 5.1 TPS software, planned patient care is executed. A window will appear for selecting the technique type (IMRT or VMAT), treatment modality (photon or electron), energy (6 MV), linac type (Elekta Infinity), and PTV (target) center. It was recommended to administer 50 Gy over 25 fractions.

Statistical analysis

The statistical analysis was used to analyze the data using Statistical Packages for the Social Sciences version 24. (SPSS-24). Simple calculations of percentage, mean, standard deviation, and range were used to represent the data (minimum-maximum values). The significance of the difference depending on means was evaluated using the paired t-test for the difference between paired observations. The p-value was considered statistically significant when it was less than or equal to 0.05.

RESULTS

The characteristics of the patients with left lung cancer included in the current study are shown in Table 1. The mean age of males was 82.6 ± 4.93 years, while the mean age of females was 72.12 ± 3.13 years. The prevalence of males was 80% and of females was 20%. The mean weight was 66.93 ± 3.84 Kg and 61.3 ± 9.27 Kg for females and males, respectively. The mean height was 172.85 ± 2.02 cm and 156.32 ± 1.21cm for males and females, respectively.

The results of the lung tumor coverage are presented in Table 2 and Figure 1. The planning target volume (PTV) for 95% and 98% represents how much the dose covers the tumor volume at a certain dose percentage. The analysis demonstrates that VMAT was significantly higher than the IMRT for the PTV 95% and PTV 98%. The PTV of 105% represents the hot area, whereas the PTV of 5% and the PTV of 2% represent the cold area. The VMAT shows a a greater hot area (PTV 105%) and cold area (PTV 2%). There was no significant difference between IMRT and VMAT for the PTV of 105%. The cold area of PTV 5% had higher dose coverage when patients were treated with the IMRT treatment planning system.

The mean, minimum, and maximum doses in Gy of VMAT were significantly higher than IMRT, as shown in (Figure 1).

The homogeneity and conformity indices were calculated using equations (1) and (2) which are presented in Table 3 and Figure 2 in order to evaluate the quality of the plan. The statistics indicate that VMAT had significantly better dose conformity (1.052 ± 0.011) and homogeneity (0.481 ± 0.218) than the IMRT for CI (0.912 ± 0.217), and (0.802 ± 0.051).

The modulation complexity score (MCS) results are presented in (Table 4) The analysis demonstrates, as depicted in (Figure 3), that the VMAT has a significantly higher MCS score than the IMRT.

Figure 4 depicts the relationship between the modulation complexity score (MCS) and the total number of monitor units

Tab. 1. Characteristics of patients

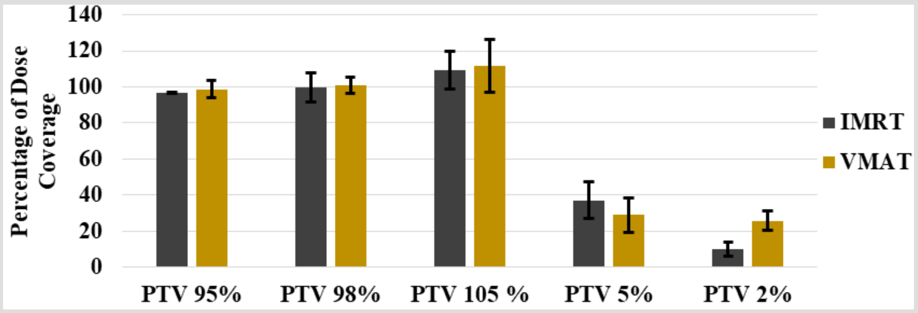
Characteristics		Mean age
Gender	Male	60%
	Female	40%
Age(Years)	Male	82.6 ± 4.93(72-98)
	Female	72.12 ± 3.13(68-77
Weight(Kg)	Male	61.3 ± 9.27(46-75)
	Female	66.93 ± 3.84(55-79)
Height(cm)	Male	172.85 ± 2.02(168-182)
	Female	156.32 ± 1.21(151-170)

Tab. 2. Comparison between IMRT and VMAT for the Dose Coverage

Parameters	IMRT	VMAT	p - Value
PTV 95%	96.912 ± 0.387	98.727 ± 4.671	0.04013*
PTV 105 %	109.37 ± 10.334	111.49 ± 14.751	0.06284
PTV 2%	9.808 ± 3.990	25.813 ± 5.566	<0.00001*

*Significant difference at p-value level equal to or less than 0.05.

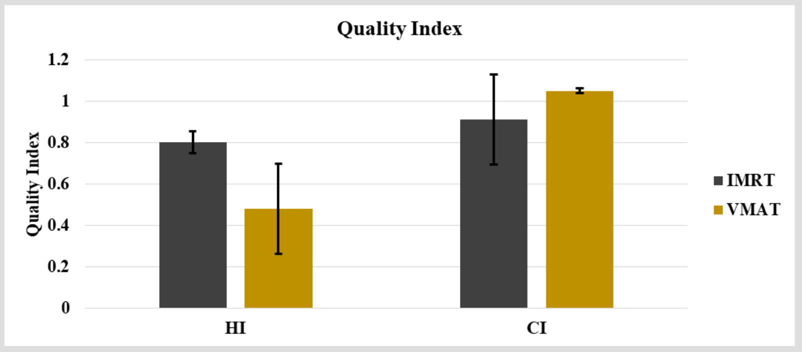
Fig. 1. Comparison between IMRT and VMAT for the Percentage of Dose Coverage



Tab. 3. Comparison between IMRT and VMAT for the Planning Quality

Quality Index	IMRT	VMAT	p - Value
HI	0.802 ± 0.051	0.481 ± 0.218	0.00022*
CI	912 ± 0.217	1.052±0.011	0.026*

Fig. 2. Comparison between IMRT and VMAT for the Quality of the Plan



in IMRT and VMAT treatment plans. According to the analysis, there is a direct correlation between the MCS and the number of MU for the IMRT technique, meaning that as the total number of MU increases, so does the modulation, with R2 = 0.0042. R2 = 0.0162 indicated an inverse relationship between the total MU and MCS for the VMAT technique.

The Table 5 presents the mean, maximum, and minimum doses for the heart, spinal cord, and contralateral lung (right) for both IMRT and VMAT techniques. (Figure 5) demonstrates that the IMRT protects the heart significantly better than the VMAT for mean and maximum doses, while the minimum dose is not significant. The mean dose to the spinal cord with VMAT is

Tab. 4. Modulation complexity score (MCS) for IMRT and VMAT

Parameters	IMRT	VMAT	p -Value
MCS	0.648±0.158	0.487±0.165	0.01895*

Fig. 3. Comparison of the MCS between the IMRT and VMAT

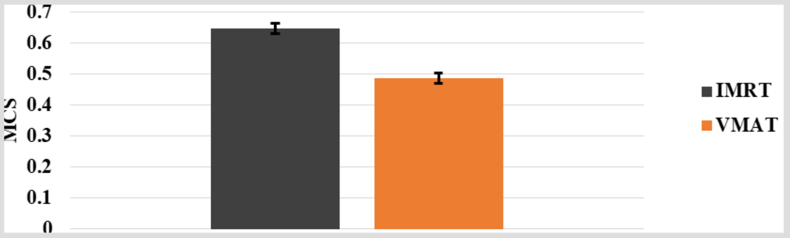


Fig. 4. Regression curve between the MCS and the total number of monitor units for the left lung with IMRT and VMAT.

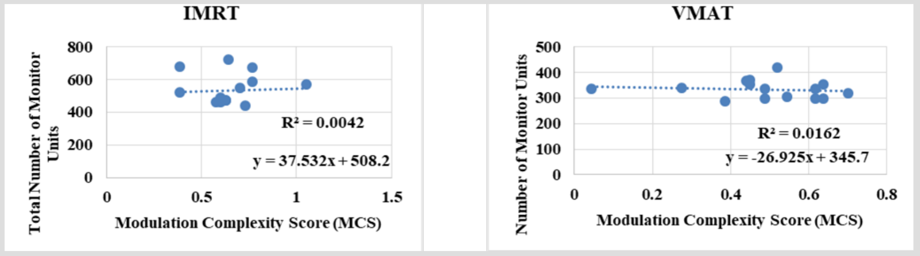


Table 5. Comparison between IMRT and VMAT for the Organs at Risk (OARs)

OARS	IMRT	VMAT	P -Value
		Heart Mean Dose	
Mean	8.239 ± 1.183	14.323 ± 2.01	0.0343*
Maximum	12.63 ± 1.44	17.93 ± 1.93	0.0500*
Minimum	2.69 ± 0.43	5.03 ± 0.94	0.0642*
		Spinal Cord Mean Dose	
Mean	8.690 ± 1.06	5.6962 ± 0.73	0.0233*
Maximum	10.02 ± 1.04	7.79 ± 0.95	0.0522*
Minimum	3.95 ± 0.89	1.09 ± 0.47	0.0579*
		Right lung (contralateral)	
Mean	25.05 ± 3.15	22.27 ± 1.86	0.0403*
Maximum	33.09 ± 6.06	29.37 ± 2.98	0.0397*
Minimum	15.04 ± 5.75	11.64 ± 3.05	0.0335*

Fig. 5. Comparison between IMRT and VMAT for Heart

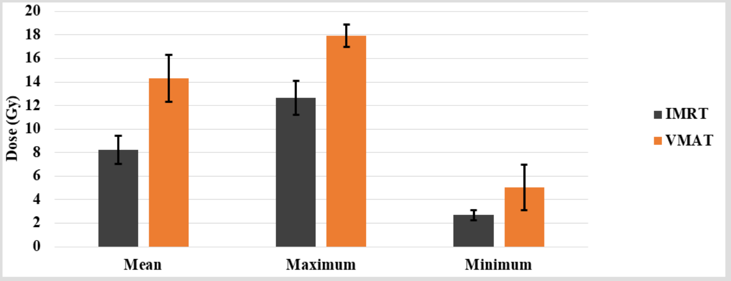


Fig. 6. Comparison between IMRT and VMAT for Spinal Cord

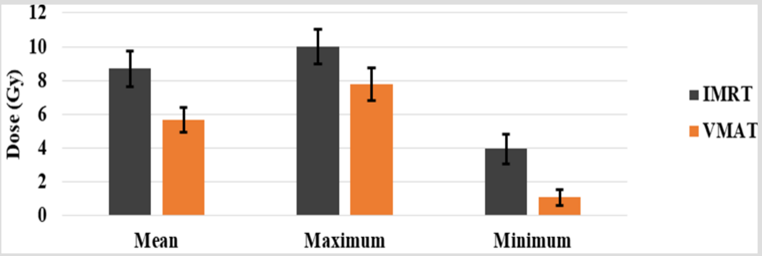
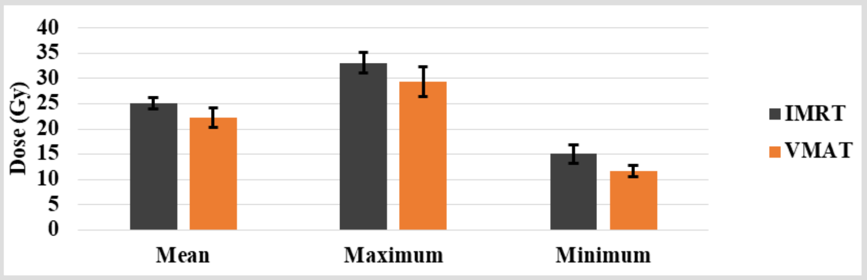


Fig. 7. Comparison between IMRT and VMAT for Right Lung (Contralateral)



significantly more effective than IMRT while there was no significant difference for maximum and minimum dose as shown in (Figure 6). The contralateral right lung receives a significantly low dose of the VMAT than the IMRT for mean, minimum, and maximum dose, as shown in (Figure 7).

DISCUSSION

The Volumetric Modulated Arc Therapy (VMAT) is used to treat a variety of solid tumors, including those with complex tumor targets, once it has been installed. The dosimetric differences between IMRT and VMAT plans for the treatment of non-small lung cancer were compared in this study, as well as the complexity of the plans, which was assessed using the modulation complexity score. In this study, it was determined that the NSLCC was more prevalent in men than in women, with a prevalence rate of 80% in men and 20% in women. The average age of women was (72.12 ± 3.13), while the average age of men was (82.6 ± 4.93).

The planning target volume (PTV) for left lung tumor coverage for 95%, 98%, 5%, and 2% demonstrates that the VMAT was significantly higher than the IMRT because the conventional IMRT using fixed or stationary fields. For the PTV 105%, there was no discernible difference between IMRT and VMAT. According to this study's statistics, the VMAT significantly outperformed the IMRT in terms of dose conformity and homogeneity. The heart, spinal cord, and lung on the opposite side were the areas of this study that received the most attention (right). While the VMAT significantly outperforms the IMRT at protecting the spinal cord, the IMRT protects the heart much better than the VMAT at mean and maximum doses but not at the lowest dose. There was no appreciable difference between the highest and lowest doses, despite the fact that the mean dosage to the spinal cord was significantly lower for VMAT than for IMRT. In this study, the VMAT strategy delivers a significantly lower mean, minimum, and maximum dose to the contralateral lung, which is the right lung, than the IMRT technique.

This study was supported by Guckenberger et al. concluded that VMAT-plan treatment was more successfully developed than IMRT-plan treatment, and Jiang et al. created partial-arc (PA) VMAT plans for assessment based on the positions of targets in an effort to further reduce treatment times [27]. Our findings demonstrate that a single arc VMAT plan treatment offers better dose coverage for the planning target volume (PTV) compared to IMRT plan treatment when it comes to radiation therapy planning for locally advanced lung cancer (the CI and HI are both better, p less than 0.05). VMAT improved the outcomes of radiation therapy for stage III NSCLC by enabling the treatment of more targets and organs at risk, which is consistent with our findings [28].

According to some researchers, Plan-optimized trajectory-based VMAT outperformed conventional VMAT and intensity-modulated radiation therapy (IMRT) in terms of conformity to the target dose and reduced irradiation dose to organs at risk [29].

According to the analysis of our study, the MCS score for the VMAT is significantly higher than that for the IMRT. For the IMRT technique, there is a direct correlation between the MCS and the total number of monitor units (MU), while for the VMAT technique, the relationship between the total number of MU and MCS is an inverse relationship.

The MCS includes segment form, area, and weight to reflect the complexity of the design for any beam delivery strategy (step-and-shoot, sliding window, or VMAT) for any organ. In this investigation, it was modified the original MCS concept for organ placement because MCS takes into account the complexity of the entire beam distribution plan [24].

The MCS concept requires the ability to provide the plan based on modifications to leaf placements and aperture regions. The complexity of the plans ranged from 1 to 0 for the simplest and the most complex, respectively [30–33]. When more pressure is applied to MLCs, high-complexity scenarios appear which increases the possibility of a catastrophic plan failure occurring during QA. When the plan is considered to be of moderate complexity, this is an indication the patient has received the required dose, whereas the dosage detected by the detector phantom will deviate from the doses anticipated by TPS to a greater extent the more complex the beam is [34,35].

To evaluate a good and homogenous dose distribution and thereby increase the MCS value, the MU for left lung designs must be decreased. This discrepancy may be caused by the fact that as the design becomes more complex, the intensity patterns' amplitude and the number of troughs increase, requiring a greater number of monitor units (MU) [34,36]. While our study focused on non-small cell lung cancer patients treated with IMRT and VMAT, IMRT has also been used for other organs, including the head, neck, and pelvis. According to the research of Mazin J. Al-baldawy, radiation causes cytoplasmic and nuclear changes in malignant cells. In this method, X-ray photons have no effect on bone mineral density.

CONCLUSION

Comparing IMRT and VMAT, volumetric modulated arc therapy (VMAT) provides superior coverage with less complexity and has the potential to preserve vital organs such as the heart, spinal cord, and right lung. In addition, it was discovered that Monitor units, also known as MUs, have an opposing effect on the modulation complexity score (MCS).

The VMAT technique may be very useful when a tumor is close to sensitive tissues or vital organs. After proper patient selection and delivery procedures have been established, the availability of VMAT services in many hospitals today makes this method simple to use.

RECOMMENDATION

Although the small sample size is a limitation of this study, the results of its analysis are encouraging. In order to support the current study and to determine if this method is a reliable source of medical examination, it is essential to conduct additional studies involving a larger number of patients, which will allow for a more comprehensive statistical analysis and thus more accurate results.

Also, additional dosimetric researches are required to improve the benefits of such a radiotherapy strategy for non-small cell lung cancer.

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