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The Effects of Whole-Lung Amplification Generated by the Addition of Left and Right Lungs in the Monaco Planning System

Ge JL[1,3], Zheng HC[2], Chen XN[2], Zhao YY[2], Xi W[2], Xu SQ[1,3*] and He RL[2*]

[1]Department of Biomedical Engineering, Chengde Medical University, China

[2]Department of Oncology, Affiliated Hospital of Chengde Medical College, China

[3]Hebei International Research Center for Medical-Engineering, Chengde Medical University, China

[*]Corresponding author:
Shi-qi Xu,
Department of Biomedical Engineering, Hebei International Research Center for Medical-Engineering, Chengde Medical University, Chengde 06700, China, E-mail: xushiqi@cdmc.edu.cn
Rui-long He,
Department of Oncology, Affiliated Hospital of Chengde Medical College, Chengde 06700, China, E-mail: chinahrl@126.com

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Keywords:

Monaco planning system; Volume error; Addition operation

1. Abstract

1.1. Purpose: To investigate the enlargement effects of the Monaco planning system on the outcome of treatment planning in the course of organ addition operation.

1.2. Materials and Methods: Based on the dose data of, the left lung, right lung, and whole lung of 30 lung cancer patients were automatically delineated using the Aicontour system, which automatically delineated. There are two types of lung delineation: one is the whole lung delineated automatically by the Aicontour system, and the other is the whole lung generated by combining the left and right lungs delineated by the Monaco planning system. The Monaco system was used to compare the results of the two whole lung models.

1.3. Results: It was found that the addition of left and right lungs would increase the total lung volume and affect the difficulty and results of planning. In the model, the entire lung was found to extend about 1-mm margin and enlarge an average of 93.83 cm3 or 3% of the total volume. The increase in lung volume was statistically significant ($P<0.05$). In terms of dosimetry, the enlarged lung volume had an impact on the planned machine hops, its target area's Conformities Index (CI) and Heterogeneity Index (HI). There was mean difference of 49 hops and maximum difference of 130 hops between two types of lung delineation, accounting for 26.5% of the total hops. The maximum CI difference reached 0.1314, accounting for 25.47% of the total. The maximum difference of HI was 0.0594, accounting for 44.29% of the total. The difference in lung V20 was up to 2%.

1.4. Conclusions: When Monaco plan is used, addition increases the size of the additive structures and the larger the size of the additive structures, finally affecting the planned machine hop count, CI and HI of the target area, and the dose of organs at risk. We should avoid using the new structure generated by the addition of structures as the optimization condition because the participation of the new structure in the optimization of the plan will cause the deviation of the plan result, which will lead to the inaccurate plan evaluation.

2. Introduction

Radiotherapy has become one of the important means of cancer treatment. The success of cancer radiotherapy mainly depends on such two factors as the design of total dose and the correct, precise and accurate application of radiation. The total dose will be limited by the tolerance of surrounding normal tissues. It is necessary to make the target area dose meet not only the requirements for clinical therapy, but also to meet the requirements for the protection of endangered organs. Therefore, the dose level applied in the target volume are related to the clinical outcome and side effects. The definition of target volume should be strictly required to reduce the dose error caused by the volume. The small deviation for the organ endangering may have little impact on the dosimetry of the clinical target, but according to the design of the scheme and the limitation is produced by the organ endangering, which is an important condition for the whole limitation target. Therefore, it is worth noting. Especially if there is serious overlap with the target structure, it should be paid more attention.

Treatment plan design in tumor radiotherapy is a complex process and is affected by many factors. Under the same software and hardware conditions of radiotherapy, the main factors that affect the difficulty of plan design are the target conditions of the treatment plan and the geometric relationship between the target area and the limited tissue structure. If the target conditions of the treatment plan are the same except the influence of human factors, the geometric relationship between the target area and the limited amount of tissue structure affects the design difficulty and results of the treatment plan, including the volume size of the target area and the limited amount of tissue structure, and the spatial relative geometric relationship, especially the volume and spatial position changes of the area coincident with the target area and the area near the target area. Clinical physiologists often make great efforts to draw a small part of the volume and a gap of less than 1mm in the clinical outline structure in the plan design. The plan results are also unsatisfactory, and even cannot design a plan that meets the target conditions of the treatment plan. Therefore, it is particularly important to accurately delineate the target area and the limited organizational structure under the same conditions. The difference in millimeters may greatly increase the difficulty of the plan, the multiple factors of the image plan output and the implementation efficiency, such as the MU of the intensity modulation plan results, the number of sub-fields, the size of sub-fields and etc.

However, the total volume of the adding organs will increase when the Monaco system performs the addition operation. Some studies show that the radiation dose in some areas of the tumor is insufficient or the adjacent normal tissue has received unnecessary high dose radiation due to the shrinking of the tumor, changes in normal tissue and the patient's nutritional status, and positioning errors and other factors during the treatment process [1-3]. When the volume of normal tissue changes, it will affect the clinical treatment effect [4]. During treatment, lung cancer patients will be subjected to the outlining of the Planned Target Volume (PTV), which is produced by uniformly extending 5-6 mm in all directions of the target area during intrapulmonary or bone metastasis, and the prescription dose covers 95% PTV. The expanded volume is accurate to mm [5] during treatment, so it will have a greater impact on the plan when the volume increases. Therefore, this study aimed to investigate the dosimetry effects of the error of addition operation using the Monaco plan system.

3. Materials and Methods

3.1. Source of Cases and Location of Radioactive Therapy

30 cases of lung cancer were selected from The Affiliated Hospital of Chengde Medical College and met the indications of radioactive therapy. Optima 520 produced by GE company was used for CT (computed tomography) location. The patients were in supine position with his head in both hands, fixed with memory membrane, scanned and sent to Monaco 5.11 system to make radioactive therapy plan.

3.2. Sketching Organs

Aicontour (version 3.1.8.0) was used to automatically sketch organs, such as the patients' left lung, right lung, whole lung and other dangerous organs. We transmitted them to Monaco system to sketch the planning target volume. We compared and analyzed the whole lungs by two automatic sketching ways of both Aicontour, and Monaco planning system of Aicontour Medical Treatment adding the left lung and the right lung. The two conditions were observed in CT images (cross section, coronal plane and sagittal plane), and their volumes were compared and analyzed. As shown in Figure 1.

3.3. Dosimetric Parameters of the Plan

30 cases were optimized by grouping plan, only the whole lung was replaced among the limiting factors, and the other conditions remained unchanged to ensure that only the whole lung was the variable in the optimization conditions of the plan. The machine hops, HI, CI of the 30 groups of plans, and the V20, V30 of lung and V30, V40 and DVH of heart of two plans were evaluated and compared.

3.4. Statistical Analysis

SPSS 26 (Statistical Program Social Sciences) was used to analyze the data, and paired T test was used to get the P value. $P<0.05$ indicates that the difference is statistically significant.

4. Results

4.1. Difference of Lung Volume

The data of lung volume of 30 patients are shown in Table 1: lungs volume sketched by Aicontour Medical System is approximately equal to the volume of left and right lungs, which can almost be ignored and not recorded. However, the average difference of lungall volume added by Monaco Planning System is 93.83 cubic centimeters, accounting for 3% of the total volume. We compared the lungs and lungall and the real lung volume by paired T-test, and the difference of lung volume increased with the lung volume enlarged ($p=0.00$). This gap can already cause great uncertainty in clinical practice. The main reason for the enlargement of lungall is the edge expansion, and the intersection of lungall and PTV will also increase.

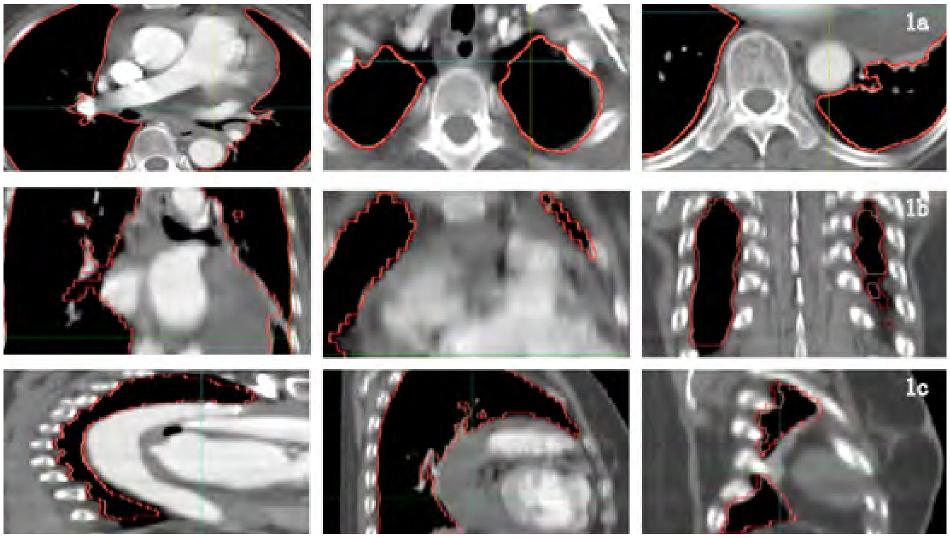


Figure 1: Local magnification of CT images of patients in different directions, i.e., cross-sectional (1a), coronal (1b), and sagittal (1c). The red line is lungall, with lungs drawn in yellow for the Aicontour medical system.

Table 1: Changes of lung volume and pulmonary difference in 30 patients

	minimum value	maximum	average	standard deviation	T	p
lung-L+lung-R(cGy)	1869.04	5446.14	3138.6	809.41	21.237	0
lungs (cGy)	1869.04	5446.53	3138.34	809.4		
lungall(cGy)	1929.98	5575.22	3232.17	825.12		
lungall-lungs(cGy)	60.94	128.69	93.83	16.46		
Proportion of pulmonary difference (%)	2.36	3.82	3.05	0.3		

4.2. I of Machine Hop Count

Machine hop count represents the output of accelerator. With the change of the number of machine hops, we can see the difficulty in the plan and the efficiency of its implementation. The output efficiency of the two plans was counted by 30 patients respectively and the line chart was counted (Figure 2). The number of machine hops in lungall is mostly larger than that in lung. With the increase of volume, the number of machine hops in the plan is also increasing and the difficulty of the plan is increasing. As shown in Table 2, the difference of machine hops is 49 hops on average, accounting for 8.1% of the total hops. Moreover, there are some individual cases with great differences, with the maximum difference of hops reaching 130 and accounting for 26.5% of the total hops. This result indicates that different lung optimization will affect the number of machine hops.

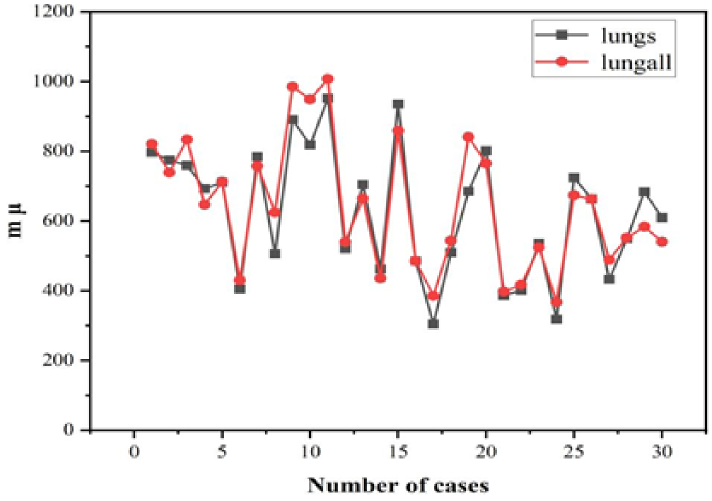


Figure 2: Machine hop count statistics of 30 cases

Table 2: Comparison of machine hop parameters under different whole lung conditions

Machine hop count								
parameter	maximum	minimum	average	standard deviation	Average difference (proportion)	Maximum difference (proportion)	T value	P value
lungs	952.17	304.5	626.71	182.1	49 (8.1%)	130 (26.5%)	-1.252	0.221
lung all	1007.21	367.05	640.96	184.6				

4.3. The Influence of PTV

We also compared the Conformity Index (CI) and the dose uniformity index (HI) of the target area. As shown in Table 3, there was no statistical difference between the calculated dose parameters under different whole lung conditions ($p>0.05$). As shown in Figures 3 and 4, the HI difference and CI difference of most cases in the figure were little, suggesting that it has little influence on the plan in most cases. However, there were three patients whose hi difference was above 0.036 and accounting for more than 26.21%, and two patients whose CI difference was above 0.132 and accounting for 25.47%. Such a gap had great clinical impact and should be avoided.

According to the analysis of two patients with great difference, the first patient adopted intensity modulation of five fields (0, 20, 50, 150, 200), and the prescribed dose was 5000cgy to cover 90% of PTV, and the other limiting factors were shown in Figure 5. The second patient was treated with seven fields of intensity modulation (200, 150, 320, 0, 30, 60, 180), and the prescribed dose was 5000cgy to cover 90% of PTV. The other limiting factors are shown in Figure 6. Only constrained operation conditions were used. In the limiting factors, only the whole lung is replaced, and the other conditions are unchanged to ensure that only the whole lung is the variable in the planning optimization conditions. In order to eliminate the deviation generated by the system in automatic planning optimization, two plans were performed on the same case under the same conditions. This ensures that the two plans were only affected by a single variable.

Its V_{ref},CI and hi were also compared, where $V_{t, ref}$ was the volume of the prescribed dose in the target area, and V_{ref} was the volume of the prescribed dose. And the intersection of different whole lungs and PTV was calculated. According to the data of Case 1 in Table 4, the difference of V_{ref} was 95.005, accounting for 17.4% of the total. The difference of CI was 0.0604, accounting for 14.8% of the total. The difference of HI was 0.0594, accounting for 57.0% of the total. Moreover, the intersection of lung and PTV was also very different.

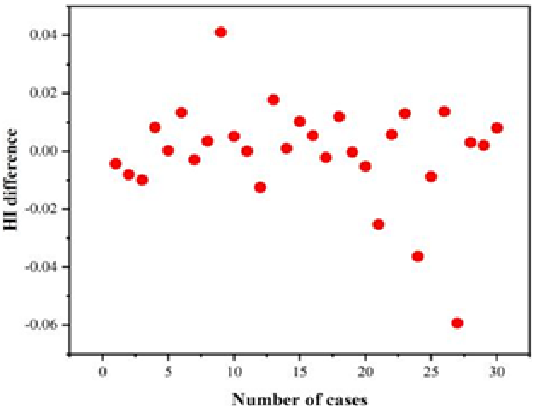


Figure 3: HI difference of 30 patients

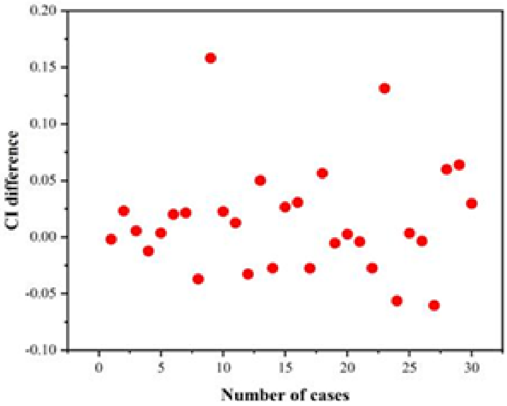
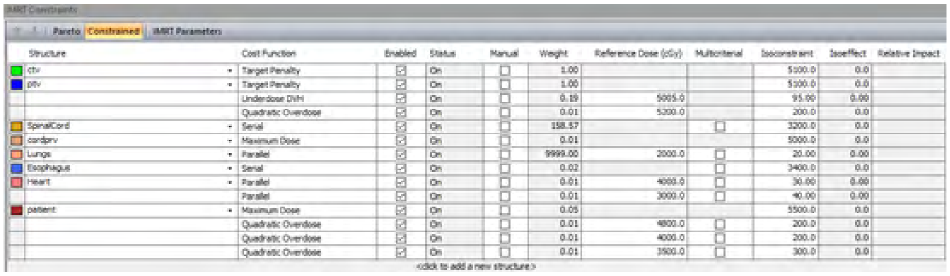
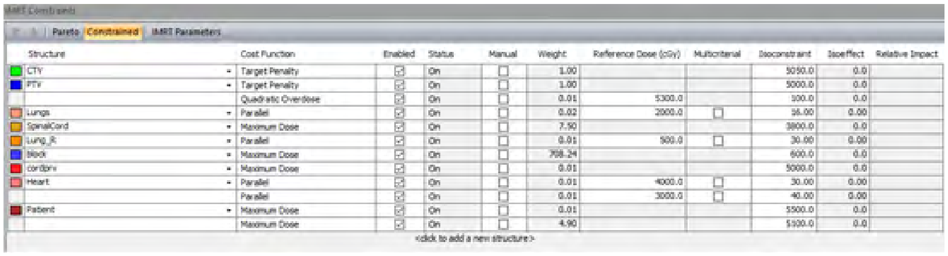


Figure 4: CI difference of 30 patients



Structure	Cost Function	Enabled	Status	Manual	Weight	Reference Dose (cGy)	Multicriterial	Isoconstraint	Isoeffect	Relative Impact
ctv	Target Penalty	☑	On	☐	1.00			5100.0	0.0	
ptv	Target Penalty	☑	On	☐	1.00			5100.0	0.0	
	Underdose DVH	☑	On	☐	0.19	5005.0		95.00	0.00	
	Quadratic Overdose	☑	On	☐	0.01	5200.0		200.0	0.0	
SpinalCord	Serial	☑	On	☐	158.57		☐	3200.0	0.0	
cordprv	Maximum Dose	☑	On	☐	0.01			5000.0	0.0	
Lungs	Parallel	☑	On	☐	9999.00	2000.0	☐	20.00	0.00	
Esophagus	Serial	☑	On	☐	0.02		☐	3400.0	0.0	
Heart	Parallel	☑	On	☐	0.01	4000.0	☐	30.00	0.00	
	Parallel	☑	On	☐	0.01	3000.0	☐	40.00	0.00	
patient	Maximum Dose	☑	On	☐	0.05			5500.0	0.0	
	Quadratic Overdose	☑	On	☐	0.01	4800.0	☐	200.0	0.0	
	Quadratic Overdose	☑	On	☐	0.01	4000.0	☐	200.0	0.0	
	Quadratic Overdose	☑	On	☐	0.01	3500.0	☐	300.0	0.0	

Figure 5: Dose limits for the first patient



Structure	Cost Function	Enabled	Status	Manual	Weight	Reference Dose (cGy)	Multicriterial	Isoconstraint	Isoeffect	Relative Impact
CTV	Target Penalty	☑	On	☐	1.00			5050.0	0.0	
PTV	Target Penalty	☑	On	☐	1.00			5000.0	0.0	
	Quadratic Overdose	☑	On	☐	0.01	5300.0		100.0	0.0	
Lungs	Parallel	☑	On	☐	0.02	2000.0	☐	16.00	0.00	
SpinalCord	Maximum Dose	☑	On	☐	7.50			3800.0	0.0	
Lung_R	Parallel	☑	On	☐	0.01	500.0	☐	30.00	0.00	
block	Maximum Dose	☑	On	☐	708.24			600.0	0.0	
cordbrv	Maximum Dose	☑	On	☐	0.01			5000.0	0.0	
Heart	Parallel	☑	On	☐	0.01	4000.0	☐	30.00	0.00	
	Parallel	☑	On	☐	0.01	3000.0	☐	40.00	0.00	
Patient	Maximum Dose	☑	On	☐	0.01			5500.0	0.0	
	Maximum Dose	☑	On	☐	4.90			5100.0	0.0	

Figure 6: Dose limits for the second patient

Table 3: Dosimetric parameters of PTV under different whole-lung conditions

PTV parameter	lungs	lungall	T value	P value
D2%	6328.03±708.6	6327.47±731.4	0.032	0.975
D98%	5558.68±602.5	5557.76±594.9	0.142	0.888
D50%	6062.57±656.2	6062.68±670.8	0.011	0.992
CI	0.58±0.13	0.56±0.13	1.621	0.116
HI	0.12±0.05	0.12±0.05	0.125	0.901

Note: Dx% is the absolute dose received within the x% volume range of the target area. HI=(D2% - D98%)/D50%,CI==$V_{t,ref}/V_t \times V_{t,ref}/V_{ref.}$ $V_{t,\ ref}$ is the volume of the target area with the received dose equal to or greater than the reference dose (unit: cm^3); V_{ref} is the volume of the received dose equal to or greater than the reference dose (unit: cm^3); V_t is the volume of target area (unit: cm^3)

Table 4: Data comparison of the two cases

Parameter	Case 1		Case 2	
	lungs	lungall	lungs	lungall
$V_{t,\ ref}$(mm^3)	232.786	232.793	115.635	115.527
V_t(mm^3)	245.041		121.633	
V_{ref}(mm^3)	639.366	544.361	178.188	185.704
lungs to PTV(mm^3)	37.473		17.331	
lungall to PTV(mm^3)	40.756		18.814	
D2%(cGy)	5728.9	5424.8	5427.5	5529.1
D98%(cGy)	4842.8	4879.1	4787.2	4814
D50%(cGy)	5415.8	5232.5	5205.5	5245.2
CI	0.3459	0.4063	0.5492	0.5292
HI	0.163613871	0.104290492	0.123004514	0.136334172
Hops	432.57	488.57	404.67	430.38

4.4. Effects of Heart and Lung

According to table 5 that in case 1, the difference of V_{20} of lung reached 2%, while that of V_{30} of heart reached 1.69%. For radiotherapy patients, a difference of 2% in the volume of lung V_{20} obviously increased the side effects of lung, especially when it is near the limited critical value. It affected the pass rate of the plan and made the plan more complicated. In case 2, the gap became smaller, but there was still be a gap, which should be paid attention to clinically.

Table 5: Cardiopulmonary data comparison of the two data

		Case 1		Case 2	
		lungs	lungall	lungs	lungall
lungs	V_{20}	23.21	21.22	9.01	8.75
	V_{30}	17.49	15.96	13.84	13.98
Heart	V_{30}	26.92	25.23	24.7	24.61
	V_{40}	18.4	19.67	17.25	18.04

4.5. Comparison of DVH

Dose-volume histograms (DVH) was an important reference for doctors to evaluate whether the plan is good or bad. According to the DVH diagram (Figure 7), DVH diagram had a great change when the restriction conditions were exactly the same (only the whole lung is used differently). It was concluded that the calculation results had changed due to the change of lung volume in Monaco operating system.

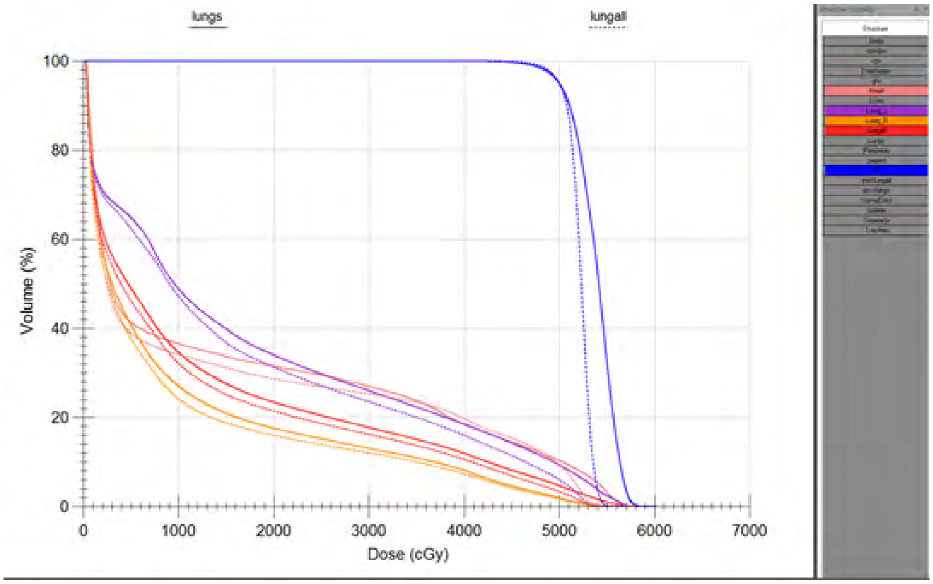


Figure 7: DVH diagram of case 1, including DVH diagrams of two types of plans, with lungs expressing the plan calculated by the total lungs formed by the interlinking system, and lungall reaching the plan calculated by the total lungs formed by the combination of the left and right lungs.

5. Discussion

For radiotherapy, the precise treatment of patients is the main purpose of the treatment, and most of the optimization is based on the positioning [6], image, linear accelerator upgrade [7] and planning system upgrade [8]. More and more data show that tumor volume and the volume of organs at risk will directly affect the design difficulty of radiotherapy plan and the result of the plan. The size of the plan will become one of the indispensable factors in the process of making radiotherapy plan [9]. No matter what kind of planning system is calculated by formula, the influence factor in the formula includes the structure volume. When the structure volume is different, a small change will cause a huge change in the result. So, we should pay attention to the change of the structure volume [10-12]. In the computer, some of the operations are performed by grid. When the structure volume increases, it seems to increase the edge by 1cm. If different grids are used, the inconsistent results will be obtained. [13-15] Ultimately, the accuracy of the planning system will be affected. The problem is an error caused by operation, and rarely encountered. In the field of radiotherapy, the continuous updating of accelerator and the continuous optimization of planning system aimed to ensure the accuracy of treatment. So, the accuracy of treatment is the ultimate goal.

In 2018, Burnet et al. [16] put forward the concept of target volume and its significance in imaging, and mentioned the importance of volume for radiotherapy. They believed that a unified outline guide should be formulated and used, and doctors and physicists should have certain standards to sketch organs. In 2017, David et al. [17] studied the dependence of stereotactic radiosurgery treatment planning system on the accuracy of volume calculation and edge growth, proposed that the edge growth of volume would affect the plan, and concluded that most plans would be affected by the excessive growth of volume. Beekman et al. [18] set up a population-based radiotherapy planning strategy library by mathematical calculation, and used this method to reduce the margin and PTV volume, so as to achieve more accurate treatment. In 2018, Guo [19] studied the different comparison of transmission and volume calculation of ROI in different planning systems and the impact on plan evaluation. It was proved that the phenomenon of organ volume expansion in the transmission process of different plans would make the plans quite different. Tan et al. [20] studied the calculation of volumes with different shapes in Monaco and pinnacle planning systems, and concluded that the sharper the outline, the greater the difference of volume calculation between the two planning systems. These findings mainly show that the volume will have a certain impact on patients, which should be paid attention to and avoided. During the treatment of lung cancer patients, the increase and uncertainty of lung dose volume will cause many clinical diseases [21-22]. However, we haven't conducted data research on the law of influence, and this problem needs further research and clinical judgment.

The above experimental results show that the volume enlargement will occur in the addition of organs in the Monaco planning system, which will have dosimetric and clinical effects on the radiotherapy planning results. In the statistics of 30 cases, we found that the average volume of the structure under the addition structure operation was 93.83 cubic centimeters, accounting for 3% of the total volume. The difference also increased with the increase of lung volume. In terms of dosimetry, the enlarged lung pair plan will have an impact on the planned machine hops and the target fitness index (CI) and dose uniformity index (HI). The average difference of machine hops in the experimental samples is 49 hops, and the enlarged lung will increase the approximate rate of machine hops, with the maximum difference of 130 hops, accounting for 26.5% of the total hops. The maximum CI difference reached 0.1314, accounting for 25.47% of the total. The maximum difference in HI reached 0.0594, accounting for 44.29% of the total. The difference of V20 in the lung is up to 2%. Therefore, we should try our best to avoid the addition operation in the structure using Monaco planning system, so as to avoid the deviation of the planned output result caused by the increase of volume which will cause inaccurate evaluation of the planned result and affect the treatment effect. Clinicians and physicists try to use suitable tripartite software or manual sketching method to avoid the uncertain influence of the above phenomena on treatment.

In conclusion, radiotherapy technology has been widely used in the treatment of tumors. The accurate delineation of target area and limited tissue structure plays a crucial role in radiotherapy. The delineation systems of various radiotherapy planning systems have more fully and functionally developed as well. In recent years, the intelligent delineation system has made rapid progress, making the organ delineation more accurate and rapid, Otherwise, the results of the radiotherapy plan will be affected and result in inaccurate treatment. When the structures are added and subtracted, there will be amplification phenomenon, and the deviation caused by the actual plan results. Most of the data show that the two plan results of our study are similar in machine hops, HI, CI, but there are still a few data indicating that there is a large gap, which can't be not ruled out and have a certain impact on the results of the radiotherapy plan. We recommend that people should try to avoid this deviation and provide a precise treatment plan for patients.

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