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Target dose accuracy of single-isocenter stereotactic body radiation therapy for multiple lung lesions

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► *Technical note*

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ABSTRACT

***Background*:** To investigate the maximum distance from lesions to the single-isocenter that can ensure the accuracy of dose delivery for single-isocenter/two-lesions intensity modulated radiotherapy (IMRT) lung stereotactic body radiation therapy (SBRT). ***Materials and Methods*:** We employed a lung phantom made of acrylic material. Sixteen gross tumor volumes (GTVs) of the same shape and size were delineated on the CT images. The single-isocenter was placed on the center of the first GTV (GTV1). Six GTV centers were located at left and were 2-7 cm away from the single-isocenter. Nine GTV centers were in the 45° direction and were 2-10 cm away from the single-isocenter. Plans were created for the first planning target volume (PTV1) and other fifteen PTVs separately with the same isocenter. Compass was used to verify the treatment plans. γ analysis was carried out with criteria of 2% / 2 mm. The passing rate shall over than 90%. If the passing rate of γ analysis was lower than 90%, two-isocenter plan was created and carried out γ analysis as well. ***Results*:** According to the γ analysis, when the distance from lesions to the single-isocenter was more than 6cm, both in the horizontal or 45° direction, the passing rate was lower than 90%. Based on γ analysis, two-isocenter plans were created. After verification, the passing rate was higher than 90%. ***Conclusions*:** The maximum distance of using single-isocenter to treat multiple lung lesions is 5 cm. The result provides a reference for our center and other centers when using this technique to treat multiple lung lesions.

INTRODUCTION

According to a report, there were more than 700,000 new cases of lung cancer in China [1,2]. Multiple lung lesions accounts for nearly 1%. Its incidence rises year by year. As a result, the studies on treating multiple lung lesions become vital.

Radiation therapy is one of the most common treatment methods for multiple lung lesions. Stereotactic Body Radiation Therapy (SBRT) is an important radiation therapy technology with many advantages [3,4]. Therefore, several clinical trials [5,6] have used SBRT to treat multiple lung lesions.

Linear-accelerator-based SBRT for a patient with multiple lung lesions is usually set up with several isocenters for treatment, and therapists setup the patient according to every isocenter in each fraction [7]. This method considerably increases the treatment time, thereby increasing the possibility of intra-fractional motion. New techniques such as intensity-modulated radiation therapy (IMRT) allow the treatment of multiple lesions by a single-isocenter plan [8], which significantly shortens the treatment time [9,10] and reduces the adverse dosimetric effect caused by intra-fractional motion.

The accuracy of dose delivery of single-isocenter plan has been studied for the treatment of multiple lesions in the brain. Gao *et al.* [11] reported that the dose delivery was accurate only when the distance between each lesion and the single isocenter was no greater than 3 cm. Calvo *et al.* [12] reported that target accuracy was within 1 mm when the distance from each lesion to the single isocenter was no greater than 6 cm. Those studies on multiple brain lesions concluded that the dose delivery would become inaccurate when the lesion-to-isocenter distance exceeded a certain threshold. However, the reported threshold values are not consistent. Additionally, given the anatomical differences between the brain and lung, the maximum distance from lesions to the single isocenter for the effective treatment of lung tissue is in urgent need of investigation.

The main purpose of this article is to study the maximum distance between lesions and the

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single-isocenter that can ensure accurate dose delivery when using SBRT technique to treat multiple lung lesions with a single-isocenter. To our knowledge, there have been no reported studies of dose delivery accuracy during the treatment of multiple lung lesions with a single-isocenter. The results of the study will provide a reference for the treatment of multiple lung lesions with single-isocenter SBRT in our center and other centers.

MATERIALS AND METHODS

Phantom design

In this study, a self-made lung phantom made of acrylic material specially designed by Topslane was used. The phantom included left lung, right lung and spinal cord. The volume of the total lung was 1477.5 cm^3 and the length of the total lung was 7.8 cm. The length of the spinal cord was 7.8 cm. The details were shown in figures 1 and 2.

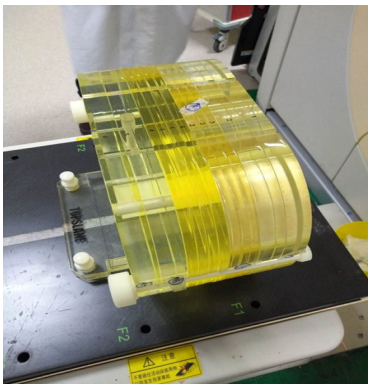

Figure 1. The real phantom using in this study.

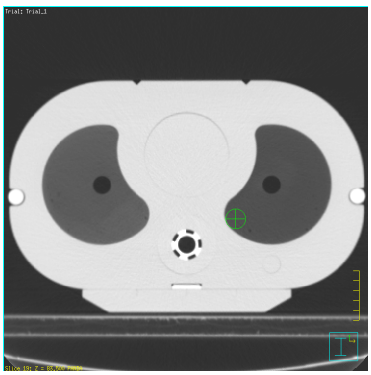

Figure 2. CT of phantom in the treatment planning system.

CT simulation and contour delineation

The phantom was placed on the CT couch and aligned to the laser light. Laser markers were affixed to the phantom to indicate the laser isocenter. Scanning was performed using the MX4000 CT Scanner System (Philips Medical Systems, Shenyang, China). The slice thickness was 2 mm and the scanning covered the entire phantom. The images were transferred via network to Pinnacle^3 treatment planning system v9.10 (Philips Healthy, Fitchburg, WI, USA).

Sixteen gross tumor volumes (GTVs) of the same shape and size were delineated on the 3D CT images. The volume of each GTV was 4.15 $cm^{(3)}$ and the equivalent diameter was about 1 cm. The single-isocenter was placed on the center of the first GTV (GTV1). Six GTV centers were located at left and were 2-7 cm away from the single-isocenter. Nine GTV centers were in the 45° direction and were 2-10 cm away from the single-isocenter. The details were shown in figure 3. Considering respiratory movement and setup error, GTVs were expanded by 0.5cm in all directions to create the planning target volume (PTV). The total lung and the spinal cord were organs at risk (OARs).

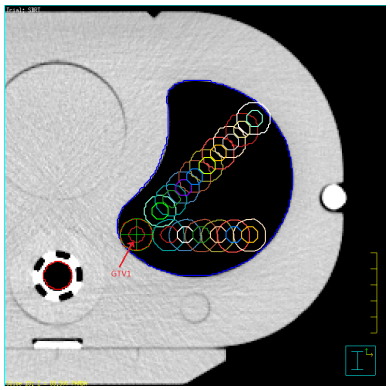

Figure 3. Contours of gross tumor volumes (GTVs), planning target volumes (PTVs) and organs at risk (OARs).

Treatment planning

Plans were created for the first planning target volume (PTV1) and other 15 PTVs separately with the single-isocenter. All plans were created using a 6 MV photon beam from an EDGE linear accelerator (Varian, Palo Alto, CA). Plans were generated using 10-13 coplanar beams. The optimization algorithm was direct machine parameter optimization (DMPO). The collapsed cone convolution (CCC) provided by Pinnacle was chosen as the dose calculation engine and the calculation grid resolution was set as 0.2×0.2×0.2 cm^3. The prescribed dose was 50 Gy in 5 fractions for PTV. Dose constraints for PTV and OARs were based on RTOG 0813 [13].

Plan verification

Compass (IBA Dosimetry GmbH, Schwarzenbruck, Germany) was used to verify the treatment planning. The system consisted of an ionization chamber detector array MatriXX suspended from an accelerator head and a set of CCC model software for dose distribution reconstruction calculation based on patient CT images. The Compass system established a virtual accelerator CCC calculation model based on the measured accelerator dose characteristics and geometric parameters, and imported IMRT plan data (including CT images, RTdose, RTplan, RTstruct, etc.)

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into the Compass system. First, the CCC model was calculated to obtain the third-party calculated dose distribution. The TPS calculation results were independently verified. After that, MatriXX was fixed on the accelerator head. When the IMRT plan was executed, MatriXX measured the fluence and used the fluence in the patient CT. The three-dimensional dose distribution was reconstructed on the image and compared with the TPS calculation results. Finally, the volume γ analysis was performed on the PTV dose distribution with criteria of 2% / 2 mm. For the γ analysis results of 2% / 2 mm, the passing rate shall not be lower than 90% [7].

Create and verification of two-isocenter plan

If the passing rate of γ analysis for the single-isocenter plan was lower than 90%, two-isocenter plan was created. For the two-isocenter plan, one isocenter was used for one lesion. Seven to eight coplanar beams were set for the two lesions respectively. All optimized conditions and dose requirements were the same as the single-isocenter plan. The plan is verified using the same verification method as the single-isocenter plan. If the passing rate was higher than 90%, it indicated that the plan create with single-isocenter was not suitable for the multiple lung lesions. So, the maximum distance from the lesions to the single-isocenter can be given.

RESULTS

In this study, a total of 17 plans were created and all of them met the requirements of RTOG 0813 [13]. γ analysis was performed using the criteria of 2% / 2 mm to verify the accuracy of the target, as shown in table 1. According to the table, if the distance from the lesion to the single-isocenter was between 2 cm and 5 cm, the passing rate was higher than 90%. But when the distance from the lesion to the single-isocenter was 6 cm, the passing rate was lower than 90%. Since in the 45° direction, the passing rate was lower than 90% when the distance from the lesion to the single-isocenter was 6 cm and 7 cm, and the distance of 8-10 cm was not verified.

Table 1. 2% / 2 mm γ analysis results.

Horizontal distance from the lesion to the single-isocenter (cm)	γ passing rate (%)	Distance from the lesion to the single-isocenter in 45° direction (cm)	γ passing rate (%)
2	90.6	2	91.8
3	91.6	3	91
4	92.4	4	91.2
5	91.4	5	90.6
6	84.9	6	85.2
7	81.1	7	80.6

When the lesion was 6 cm away from the single-isocenter, γ analysis with criteria of 2% / 2 mm had a passing rate lower than 90%. Therefore, two-isocenter plan was created and verified. In the horizontal direction and 45° direction, γ analysis results were 90.8% and 90.5% respectively. The passing rate of two-isocenter plan was higher than 90%. Thus, it is concluded that the maximum distance of using single-isocenter to treat multiple lung lesion was 5 cm.

DISCUSSION

The incidence of multiple lung lesions is increasing year over year. With the development of technology, some researchers have begun to investigate the use of single-isocenter to treat multiple tumors. There have been studies [11,12] on the dose accuracy of single-isocenter treatment of multiple brain metastases. However, regarding the use of single-isocenter to treat multiple lung lesions, there is no research on the maximum distance from the lung lesions to the single-isocenter that can guarantee accurate dose delivery. This is the starting point and foothold of this study.

The lung phantom used in this study was specially customized by Topslane. The phantom contained tatal lung and spinal cord, which was more similar to the actual condition of the patient. This lung phantom was more authentic than a traditional phantom composed of acrylic blocks, enabling a better evaluation of whether the treatment plan met the requirements, as well as a more convincing conclusion.

The COMPASS system is a commonly used IMRT dose verification tool. For γ analysis of conventional fractionation IMRT plans, a criteria of 3%/3 mm are usually chosen [14,15]. For SBRT plans, because of the steeper dose gradient and the higher requirement for dose accuracy, the criteria of 2%/2 mm are selected [16,17]. In this study, SBRT technology was used to perform a γ analysis with the criterion of 2%/2 mm.

This study is the first to determine the maximum lesion-single-isocenter distance that ensures accurate dose in single-isocenter radiotherapy for multiple lung lesions. The results showed that when the distance between a lesion and the single isocenter was less than or equal to 5 cm, the γ pass rate was higher than 90%. When the distance between a lesion and the single-isocenter exceeded 5 cm, the γ pass rate was less than 90%. Therefore, in order to ensure dose accuracy, when the distance between lesion and the single-isocenter exceeds 5 cm in our department, the treatment planning should be designed with dual isocenters. Gao *et al.* [11] and Calvo *et al.* [12] directly selected 3 cm and 6 cm as the resigned objects but did not study any other distances. Ezzell [18] used single-center SRS to treat patients with multiple brain metastases and studied its spatial accuracy on a phantom. It was found that as the distance between the lesion and the single-isocenter increased, the

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spatial difference increased. This prior finding is similar to the results of this study.

Due to the strict requirements of the high standard of SBRT, the integrated accuracy of the isocenter, gantry and couch of the EDGE Linac was within 0.05 cm, which was higher than that of the general Linac. Furthermore, the rigorous and comprehensive QA of Linac is also beneficial for ensuring high accuracy. Therefore, the results of this study were obtained based on this high-precision Linac. Linacs with different accuracy may produce different results.

There are some limitations in this study. Firstly, the phantom used in this study did not enable us to consider the effect of respiratory movement, internal motion and some other factors. When all the factors were considered, this maximum distance could be much shorter. Secondly, 10-13 coplanar beams were used for each plan in this study, while actually using more beams may increase the complexity of the plan and even change the results. Despite the limitations mentioned above, this study is still very meaningful. We have raised a very interesting question, and we will continue to investigate this question in the future.

CONCLUSIONS

This study shows that the maximum lesion-to-isocenter distance is 5cm to guarantee the dose accuracy of 90% in GPR, for the treatment of multiple lung lesions with single-isocenter SBRT plan. The results of this study can serve as a reference for people who use this technique to treat multiple lung lesions with the single-isocenter in our center and other centers.

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***Ethical considerations*:** The study was approved by the institutional ethics committee.

***Conflicts of interest*:** *Declared none.*

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