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The influence of respiratory motion on dose distribution of 3D-CRT and IMRT- A simulation study

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► ***Original article***

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ABSTRACT

Background: 3DCRT (three-dimensional conformal radiotherapy) and IMRT (intensity-modulated radiotherapy) has provided us with tools to delineate the radiation dose distribution of tumor targets. However, the precision of radiation can be compromised by respiratory motion, which usually limits the geometric and dosimetric accuracy of radiotherapy. The purpose of this study is to evaluate the impact of respiratory motion on dose distributions of 3D-CRT and dynamic IMRT by simulating the respiratory motion, and provide suggestions to optimize treatment planning. ***Materials and Methods:*** American Sun Nuclear Mapcheck 2D-ARRAY was placed on a moving platform to simulate the respiratory motion. The dose distributions were measured with a Sun Nuclear Mapcheck 2D-ARRAY on the moving platform. The motion cycle was 3.5s, the amplitude was ±3mm, ±5mm, ±10mm, ±15mm. Dosimetric distribution between 3DCRT and IMRT plans were contrasted byγ-passing rate analysis. SPSS 13.0 software was used for data processing and analysis. ***Results:*** The respiratory motion could blur the target dose distribution of 3D-CRT and IMRT. The pass rate (3% 3mm) in 3DCRT was larger than that in IMRT. The Mapcheck software reflected that, the respiratory motion largely affected the marginal dose distribution of 3D-CRT, while affected the whole target volumes of IMRT. ***Conclusions:*** Respiratory motion has a greater impact on the dose distribution of IMRT than on 3D-CRT. As for tumors with large motion amplitude, it is advisable to use 3DCRT rather than IMRT techniques.

Keywords: *Respiratory motion, 3DCRT, DIMRT, Dose distribution.*

INTRODUCTION

Radiotherapy, especially the invention of 3-dimensional conformal radiotherapy (3DCRT) and intensity-modulated radiotherapy (IMRT), as the widely accepted technique for many thoracic malignancies [1], has provided us with tools to deliver dose to the target with high precision, so that we can elevate the dose of tumor while minimizing the dose of the surrounding healthy tissues as far as possible [2]. However, the success of 3DCRT and IMRT can be compromised by respiratory motion, which usually limits the geometric and dosimetric accuracy of radiotherapy and has become an urgent issue for tumor treatment [3,4].

In recent years advances in technology have spawned new types of strategies to compensate the influence of respiratory motion, such as deep inspiration breath-hold [5,6], respiratory gating [6,7], real-time tumor tracking [8,9], four-dimensional radiotherapy [9,10]. Of course, there is another approach [2] to account for motion, which, in essence, considers the motion effects on the dose distribution during the radiotherapy planning process, thereby assuring the dose delivered is matched with the dose planned or just reducing the influence of respiratory motion by optimizing the treatment parameters.

Taking what mentioned above into considera-

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tion, in this paper, we adopted 2D semiconductor matrix Mapchecker system and simulative respiratory motion platform to quantitatively evaluate the influence of respiratory motion on dose distribution in 3DCRT and Dynamic IMRT. The overall results may provide a reference for clinical oncologists to precisely delineate tumor target and select more sensible treatment plans.

MATERIALS AND METHODS

Equipments

2-dimentional semiconductor matrix Mapchecker system (Sun Nuclear, USA), a simulative respiratory motion platform (supplied by Shenzhen Instar Electromechanical Technical Development Co., Ltd), Varian 23IX linear accelerator (6MV X-ray, 120 leaves, 5mm/leaf), Varian Eclipse8.0 treatment planning system (TPS), a square model of solid water with 30cm side length and 3cm thickness.

Motion system design and operation

11 lung cancer patients were selected as a validation group, of whom the 3D image data was obtained by CT scan and delivered to TPS. Once determining gross tumor volume (GTV) and organs at risk (OAR), we design a homogeneous 3D-CRT and D-IMRT plan. After we acquired the 3D image data of virtual solid water phantom in the same way, adopting previous established 3D-CRT and D-IMRT plan. Then choose 3cm below horizontal surface as isocenter, set gantry angle to 0°and create 2 QA plans (3DCRT-QA and DIMRT-QA), assuring the single fraction dose of QA plan was consistent with that of TPS. Output QA plan and the dose distribution matrix diagram in isocentral horizon of TPS.

dose verification

A stringent inspection of mechanical properties such as MLC leaves was accomplished at 0° gantry angle, conforming to AAPM international criteria for quality control [11]. Mapcheck system was adopted to measure the surface dose of 10cm×10cm standard field, calibrating actual surface dose equal to TPS surface dose, hence the passing rate was 100%.

With Mapchecker on the platform, the simulative respiratory motion platform was placed just below the collimator field. Then a 3cm equivalent water phantom, put on Mapchecker, was set up as if it was standing on its lung, with the diaphragmatic motion along the horizonal axis. LA couch was modulated, so that the probe located at isocenter. Keep the accelerator gantry angle always at 0°, two verifications were made for each field coherently on the basis of QA plan. The first was routine verification, with the simulative motion phantom being static; while the second was done on condition that the phantom moved periodically. The motion cycle was set to 3.5s, and motion amplitude was ±3mm, ±5mm, ±10mm, ±15 mm respectively, which just resembled the motion cycle and amplitude of tumors in lung apex, upper lobe , middle and lower lobe. The IMRT and 3DCRT plans were both delivered on the same day with Varian linear accelerator, in step-and -shoot mode. After the measurement of the dose distribution of each single field and overlapping field in 3DCRT and the dose distribution of TPS single field and all overlapping subfields in DIMRT, the data was analyzed comparatively.

Data analysis

Isodose superposition method [12] and surface dose verification were adopted to measure the γ-passing rate (3mm/3%).

Statistical analysis

We use paired t-test based on SPSS 17.0 software to compare the γ-passing rate between 3DCRT and DIMRT, and $P<0.05$ was statistically significant.

RESULTS

Respiratory motion blurred the dose distribution of 3DCRT and IMRT

The dose distribution and the γ-passing rate of isocentral surface between static and motion state, obtained by Mapchecker system are shown in figures 1 and 2. According to the results, respiratory motion blurred the dose distribution of

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target, reduced dose conformity of 3DCRT and IMRT and also obviously diminished the γ–passing rate of dose throughput. Beyond that, from an overall perspective about the two figures, the impact on IMRT covers the whole target, while the influence on 3DCRT generally distributed in peripheral target.

As following, table 1 and table 2 displayed the γ-passing rate of 3DCRT and DIMRT at static and motion state (amplitude = ±10mm, motion cycle = 3.5s), indicating that respiratory motion lowered the γ-passing rate of 3DCRT and DIMRT, yet the decrease of DIMRT appeared to be more remarkable.

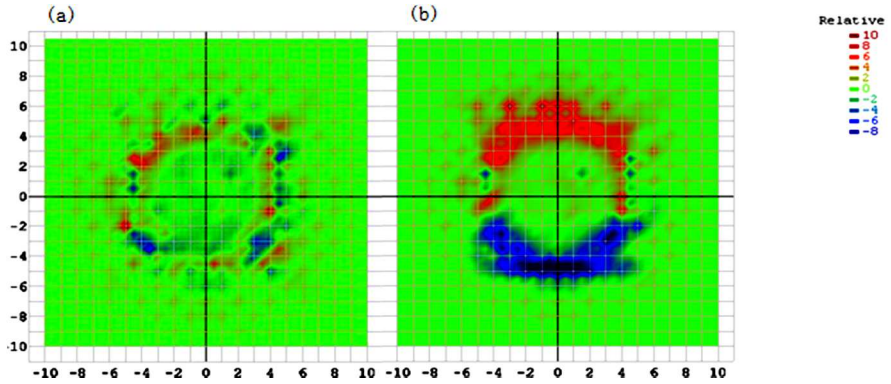

Figure 1. (a) static state, the dose distribution of 3DCRT and TPS(γ-passing rate=97.8%), (b) motion state, the dose distribution of 3DCRT and TPS(γ-passing rate=74.5%) .

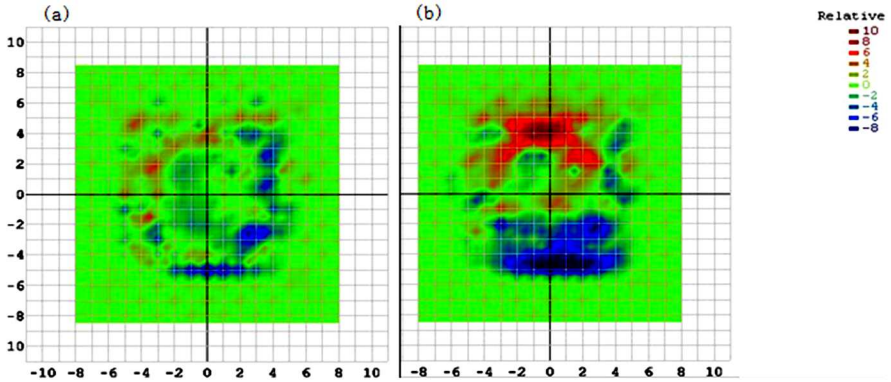

Figure 2. (a) static state, the dose distribution of DIMRT and TPS(γ-passing rate=96.5%), (b) motion state, the dose distribution of DIMRT and TPS(γ-passing rate=61.2%)

Table 1. 3DCRT γ-passing rate of a lung cancer patient at static and motion state (amplitude=±10mm, motion cycle=3.5s).

State	*field1*	*field 2*	*field 3*	*field 4*	*field 5*	average
static	98.1	100	92.5	93.9	95.6	96.02
motion	75.2	79.1	72.8	74.1	74.5	75.14

Table 2. DIMRT γ-passing rate of a lung cancer patient at static and motion state (amplitude=±10mm, motion cycle=3.5s).

State	*field1*	*field 2*	*field 3*	*field 4*	*field 5*	average
static	96.2	98.5	91.3	92.5	93.8	94.46
motion	65.3	68.7	60.8	62.5	63.9	64.24

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Impact of respiratory motion on the dose distribution of IMRT and 3D-CRT

For further impact of respiratory motion on dose distribution, the γ-passing rate related to 11 lung treatment cases of different motion amplitudes are shown in table 3, with 3mm/3% as a standard.

Based on the analysis of paired *t-test*, the γ-passing rates between 3DCRT and DIMRT are summarized in table 4. The overall results revealed that the γ-passing rates of the two treatment plans were statistically different (P<0.05), which obviously meant respiratory motion had a greater impact on the dose distribution of IMRT than on 3D-CRT. Additionally, the measurement results also exhibited that bigger motion amplitudes led to a higher degree of dose blurring.

DISCUSSION

Intensity-modulated radiotherapy (IMRT) and 3-dimensional conformal radiotherapy (3DCRT) have been proved effective for delivering radiation dose with a high degree of conformity to target volumes, while keeping normal tissues within tolerance levels [1,2,13,14]. However, the complicated and unpredictable respiratory motion, can lead to geometric and anatomic variations, which may well blur optimal target volume coverage [3,4,15,16] and have turned into the current challenge in high-precision 3DCRT and IMRT.

In this paper, we quantitatively evaluate the influence of respiratory motion on dose distribution in 3DCRT and Dynamic IMRT. Results show that the respiratory motion can blur the target dose distribution and bigger motion amplitudes tend to cause a higher degree of dose blurring in Dynamic IMRT. A proper reason for this is that respiratory motion will compromise the dose conformity of tumor target and lead to obvious contrast between actual dosimetry and static PTV dose distribution, which can easily be understood through an analogy with photography [2,3]: when we take pictures of a moving object, the image will be blurred. The bigger motion amplitudes are, the more the image blurs. Similarly, if the motion amplitude was lower, such as ±3mm, target of both 3DCRT and IMRT can receive relatively accurate radiation.

Furthermore, respiratory motion, affecting the marginal dose distribution of 3D-CRT rather than the whole target volumes of IMRT, appar-

Table 3. γ-passing rate of 11 lung cancer patients at motion state.

radiotherapy	*amplitude*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*
3DCRT	±3mm	98.2	96.5	99.6	97.9	100	99.8	95.1	92.5	96.3	93.7	91.5
DIMRT	±3mm	91.1	90.5	92.5	91.0	92.3	91.8	90.8	89.6	90.6	89.6	88.3
3DCRT	±5mm	94.5	92.9	95.1	93.6	96.7	95.5	90.3	86.9	92.7	89.2	85.1
DIMRT	±5mm	82.6	82.0	83.6	82.3	84.1	83.2	80.2	78.8	81.1	80.5	76.5
3DCRT	±10mm	74.5	72.1	76.8	72.6	74.2	73.7	75.5	79.1	73.9	73.5	78.6
DIMRT	±10mm	61.2	61.5	65.8	62.4	60.9	63.1	62.7	67.7	62.8	61.7	66.1
3DCRT	±15mm	63.8	60.7	61.5	64.1	58.5	55.4	62.5	58.9	60.1	62.9	50.4
DIMRT	±15mm	32.7	30.2	30.9	33.3	28.7	27.3	31.4	29.2	29.6.	31.6	26.8

Table 4. The analysis of paired *t-test* about the γ-passing rate in table 3.

radiotherapy	*amplitude*	*γ-passing rate*	*paired t-test*	*P*
3DCRT	±3mm	(96.46±2.97)%	t=10.40	P<0.05
DIMRT	±3mm	(90.74±1.24)%		
3DCRT	±5mm	(92.05±3.72)%	t=22.43	P<0.05
DIMRT	±5mm	(81.35±2.26)%		
3DCRT	±10mm	(74.96±2.31)%	t=34.56	P<0.05
DIMRT	±10mm	(63.26±2.26)%		
3DCRT	±15mm	(59.89±4.07)%	t=44.31	P<0.05
DIMRT	±15mm	(30.16±2.08)%		

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ently has a greater impact on IMRT. For the same motion amplitude, MLC, comprising the IMRT plan, can outstretch the GTV, thus respiratory motion may lead to under-dose or over-dose of irradiation as well as influencing the dose distribution of the whole target volumes in IMRT. In other words, MLC can introduce high-dose areas to the motion-averaged distributions in the GTV, which have resulted from booster segments exposing the area surrounding the GTV [3].

CONCLUSION

A carefully designed simulated experiment to study the influence of respiratory motion on dose distribution in 3D-CRT and IMRT has been presented.

The respiratory motion has the more pronounced effect on blurring the dose distribution of IMRT than on 3D-CRT and bigger motion amplitudes tend to cause a higher degree of dose blurring. In consequence, motion amplitude should be taken into account when designing treatment plans, moreover, CTV and dose distribution should be calibrated. If respiratory gating control is not available, as for tumors with large motion amplitude, 3DCRT may be superior to IMRT.

Conflict of interest: *Declared none*

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