Dosimetric Analysis on the Effect of Target Motion in the Fixed-beam IMRT, RapidArc and Tomotherapy

J. SONG
Department of Radiation Oncology, Chonnam National University Medical School, Gwangju, Korea

JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

In the case of ITV-based radiotherapy, the dose distribution of the general 3-dimensional conformal radiotherapy (3D CRT) is considered to be the same as the calculated dose distribution in the treatment area. However, when the dose distribution changes dynamically according to the motion of the multi-leaf collimator (MLC) as in the intensity-modulated radiotherapy (IMRT), the change in the actual dose distribution due to tumor movement is expected to be significant

AIM

To analyze the dose variation due to the respiratory motion in the internal target volume (ITV)-based IMRT treatment by comparing with the calculated dose distribution in the plan according to the IMRT performance techniques

METHOD

Three different ITV-based IMRT plans, a fixed-beam (FB) IMRT, a volumetric modulated arc therapy (VMAT), and tomotherapy using helical therapy were prepared separately. I'mRT Phantom (IBA, Schwarzenbruck, Germany) CT images were acquired and IMRT treatment plans were prepared by creating a virtual tumor target and peripheral OARs, as shown in Fig 1.

Delivery quality assurance (DQA) plans were established for these treatment plans. The dose distribution in the actual motion condition was measured and analyzed using a two-dimensional diode detector placed on a moving phantom capable of simulating breathing movements.

The dose variations were compared and analyzed for each treatment method in order to evaluate the effect of a target motion on the IMRT dosimetric error.

The dose measurement was performed considering only a uniform target shape and motion in the superior-inferior (SI) direction.

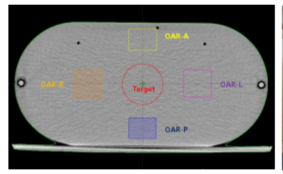

Fig. 1.

Fig. 2.

Fig. 3.

Fig. 1. Virtual tumor target and OARs for the preparation of IMRT plan.
Fig. 2. Phantom setup image for the dose measurement in the Novalis Tx.
Fig. 3. Phantom setup image for the dose measurement in the Tomotherapy.

RESULTS

The dose distribution measured with MapCHECK2 under various motion conditions was slightly different for each treatment method, and Fig 4 shows an example of these different results.

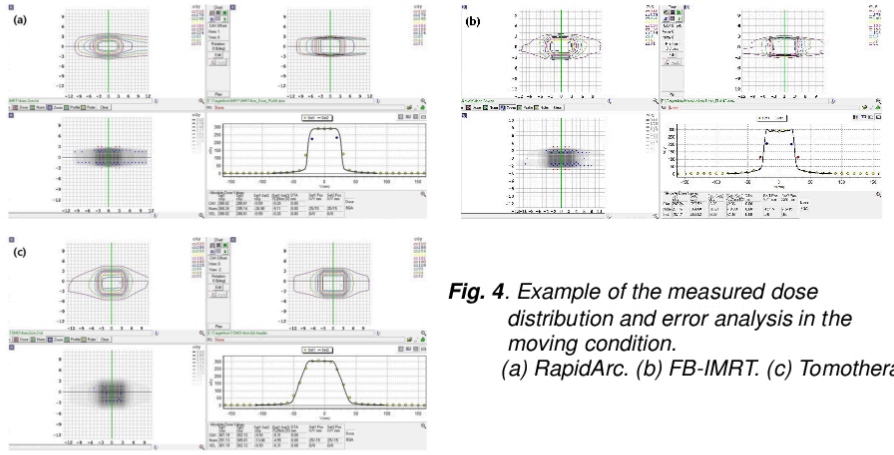

***Fig. 4**. Example of the measured dose distribution and error analysis in the moving condition. (a) RapidArc. (b) FB-IMRT. (c) Tomotherapy.*

The calculated pass rates by the gamma evaluation for each clinical target volume (CTV) tumor size in the condition of motion are shown in Tables 1, 2, and 3.

Table 1. The calculated pass rates by the gamma evaluation for the CTV with 2 cm length in the condition of motion.

	ITV length	Static Condition	7 sec Motion Period		4 sec Motion Period	
			4cm Range	2cm Range	4cm Range	2cm Range
RapidArc	4 cm	100.0%		77.7%		76.0%
	6 cm	99.7%	59.0%		60.2%	
FB-IMRT	4 cm	100.0%		76.7%		77.1%
	6 cm	100.0%	55.9%		55.6%	
Tomotherapy	4 cm	100.0%		96.3%		96.6%
	6 cm	100.0%	83.0%		82.0%	

Table 2. The calculated pass rates by the gamma evaluation for the CTV with 4 cm length in the condition of motion.

	ITV length	Static Condition	7 sec Motion Period		4 sec Motion Period	
			4cm Range	2cm Range	4cm Range	2cm Range
RapidArc	6 cm	99.7%		83.3%		82.4%
	8 cm	99.5%	65.5%		70.0%	
FB-IMRT	6 cm	100.0%		82.2%		81.9%
	8 cm	100.0%	67.0%%		67.0%	
Tomotherapy	6 cm	100.0%		95.7%		95.9%
	8 cm	100.0%	83.6%		83.7%	

Table 3. The calculated pass rates by the gamma evaluation for the CTV with 6 cm length in the condition of motion.

	ITV length	Static Condition	7 sec Motion Period	4 sec Motion Period
			2cm Range	2cm Range
RapidArc	8 cm	99.5%	83.1%	86.1%
FB-IMRT	8 cm	100.0%	88.4%	86.0%
Tomotherapy	8 cm	100.0%	94.5%	95.8%

As shown in the pass rates of the tables, the average difference in pass rate between the 4 s and 7 s period was 0.18 ± 0.73% in the case of tomotherapy, 1.44 ± 2.16% in the case of RapidArc, and -0.52 ± 0.97% in the case of FB-IMRT. For RapidArc, the pass rate difference at 4 s was slightly higher than those for tomotherapy and FB-IMRT, but the mean of the overall difference was 0.29 ± 1.73%, indicating that the change in motion period had little effect on dose accuracy.

The factors that have the greatest influence on the dose distribution in the motion condition are the magnitude of motion range, which can be confirmed in the table results. It was confirmed that the dose error was further increased with increasing motion range because the pass rate was lower at the 4-cm motion range than at the 2-cm motion range.

The degree to which the error increased with increasing motion range showed different tendencies according to the treatment method. In the case of tomotherapy, the mean pass rate was 83.08 ± 0.78% at the 4-cm motion range and 95.80 ± 0.72% at the 2-cm motion range. In the case of RapidArc, the mean pass rate was 63.68 ± 5.08% at the 4-cm motion range and 81.43 ± 3.81% at the 2-cm motion range. For FB-IMRT, the average pass rate was 61.38 ± 6.49% for 4 cm motion range and 82.05 ± 4.67% for 2 cm motion range. As shown by the above results, the tendency of the dose error increase with the increase in the motion displacement from 2 cm to 4 cm was different according to the treatment technique. The mean decrease in pass rate was -12.50 ± 1.19% in the case of tomotherapy, -18.88 ± 8.27% in the case of RapidArc, and -21.95 ± 8.96% in the case of FB-IMRT. These results show that the dose error due to the increase in the motion range was relatively small in tomotherapy compared to those in RapidArc and FB-IMRT.

The effect of target motion according to the CTV increase due to CTV length increase is shown in Fig. 5. In the case of the 2-cm motion range, the dosimetric error according to the decrease in CTV increased by 0.8% in tomotherapy, 7.7% in RapidArc, and 10.3% in FB-IMRT. In the case of 4-cm motion range, the dosimetric error according to the decrease in CTV increased by 0.2% in tomotherapy, 8.2% in RapidArc and 11.2% in FB-IMRT. Although there was no significant difference in tomotherapy, the pass rate was lower and the dosimetric error was relatively increased in the case of RapidArc and FB-IMRT, as the CTV was smaller due to the shorter CTV length.

RESULTS

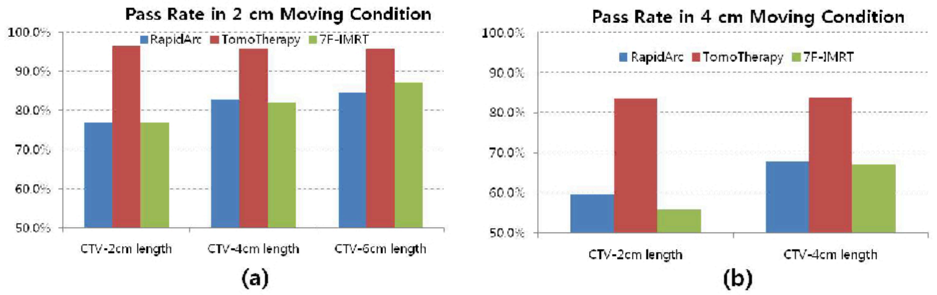

***Fig. 5**. Graphs showing the effect of target motion according to the CTV increase due to CTV length increase. (a) Pass rate in 2 cm moving condition. (b) Pass rate in 4 cm moving condition.*

Because the shape of the target used in this study was relatively uniform and the motion direction was considered only in the SI direction, the change in dose due to motion mainly occurred at the tip of the target. However, the pattern showed slightly different dose changes according to the characteristics of the tomotherapy, RapidArc and FB-IMRT treatment methods. Since FB-IMRT and RapidArc deliver the treatment beam for the entire target, the point where the dose distribution error by gamma evaluation exceeds the reference value is more widely spatially distributed. Owing to the characteristics of the helical treatment method, tomotherapy was mainly distributed to the dose error point in the target moving SI direction, and the dose error at the end positions of the target was dominant. This was thought to be the cause of the smallest change in dose with tumor motion in tomotherapy among the three types of IMRT treatment. The target motion in a relatively uniform shape is considered to cause a relatively low dose distribution error due to motion in tomotherapy, compared to the case where the IMRT dose is irradiated to the entire target in the treatment process. This is due to the characteristic of the helical therapy, which treats multiple sectors of the target sequentially.

CONCLUSIONS

Among the various ITV-based IMRT methods, it was confirmed by real dose measurements under motion conditions that the tomotherapy method has a relative advantage in the dosimetric accuracy compared to the general FB-IMRT or VMAT-type RapidArc methods in the case of a homogeneously shaped target.

When the target shape is relatively uniform and the motion is mainly in the SI direction during the tomotherapy treatment, the ITV could be slightly extended in the SI direction, considering the length of the motion range. This method could effectively reduce the dose error at both end regions of the original ITV.

CONTACT INFORMATION

Ju-Young Song (E-mail: jysong@jnu.ac.kr, TEL: 82-10-4231-4529