Nuclear Science and Techniques 20 (2009) 297–301

Data analysis of dose map verification for IMRT

XU Yingjie DAI Jianrong* FU Guishan ZHANG Yongqian ZHANG Ke
CUI Weijie ZHANG Dandan JIANG Bo

Department of Radiation Oncology, Cancer Institute, Chinese Academy of Medical Science, Beijing 100021, China

Abstract In this paper we analyze the results of dose map verifications for patient's IMRT (Intensity-modulated radiation therap**y)** plans and study the factors that may influence the accuracy of verification. MapCHECK, a two-dimensional diode array, was used to measure the dose maps for 1242 plans (14540 fields) from May 2004 to August 2008. The plans were designed with Pinnacle^3 planning system. The passing rate of beams was determined when the acceptance criterion was 2%/2 mm, 3%/3 mm and 4%/4 mm. And the data with 3%/3 mm criteria was analyzed in more detail. The considered factors were beam modeling, optimization mode and treatment site. The median passing rate of total fields was 93.5%, 98.8%, and 100% when the acceptance criterion was 2%/2 mm, 3%/3 mm and 4%/4 mm, and the interquartile range were 11.1%, 3.8%, and 1.3%, respectively. The results of direct machine parameter optimization (DMPO) planning mode was better than those of multiple-step mode and beam modeling of new accelerators was better than that of old accelerators. These indicate that beam modeling is the key point of improving passing rate of IMRT verification and the influence of treatment site was little. The factors, the total number of segments, minimum area of segments and minimum monitor unit (MU) of segments, also influence the dosimetric accuracy of IMRT plan verification.

Key words Dose map verification, Intensity-modulated radiation therapy, Beam modeling

1 Introduction

Intensity-modulated radiation therapy (IMRT) achieves desired dose distribution in a complex-shaped volume by modulating the intensity map of each treatment field. However, it is complicated than conventional 3D conformal radiotherapy in treatment planning and delivery. A dose verification is indispensable for each individual patient's plan, and this is often done by measuring two-dimensional (2D) dose map in a plane perpendicular to beam axis for each treatment field of the patient's plan. The dosimetry systems include films[1], diode arrays[2,3], ionization chamber arrays[4] and electronic portal imaging devices[5]. A film system is of the highest special resolution, but the processes procedure, unlike the other three systems, is labor intensive due to non-real-time.

Since May 2004, we have been using MapCHECK to verify dose distributions for patient IMRT plans. As of August 2008, 14540 IMRT treatment fields of 1242 patient plans were verified. This investigation is to review the verification results of these fields and to identify the factors that may influence the accuracy of IMRT verification.

2 Methods and material

2.1 Patient and treatment characteristics

Of the 1242 IMRT patient QA plans, 618 were for head and neck tumors, 132 for thoracic tumors, and 492 for abdominal and pelvic tumors. All plans were designed with Pinnacle^3 (Version 7.4, or 8.0 m) for static delivery. The planning mode was multiple-step mode (optimize fluence maps, transform fluence maps into leaf sequences, with or without optimizing segment weight) before January 2005. Since then the planning mode has been changed to the mode of direct

* Corresponding author. *E-mail address:* dai_jianrong@163.com

Received date: 2009-05-11

machine parameter optimization (DMPO), or direct-aperture optimization as it is called in the literatures. The plans were delivered with 6 MV X-rays from a linac of either Siemens Primus, Elekta Precise, Varian 600CD or Elekta Synergy.

2.2 Measurement equipment

MapCHECK, a 2D diode array, was used to verify dose map distribution for IMRT plans. It consists of 445 N-type diodes distributed over an area of 22 cm × 22 cm. The 10 cm×10 cm center array contains 221 diodes with 7.07-mm spacing, and the outer array ring contains 224 diodes with 14.14-mm spacing[6]. Dose response of the diodes is linear for doses up to 295cGy[3]. The diode plane has a 2-cm thick water-equivalent buildup material and a 2.7-cm thick water-equivalent backscattering material.

2.3 Measurement procedure

2.3.1 In-phantom calculations

A homogeneous water phantom was established for the Pinnacle^3 treatment planning system (TPS). A patient IMRT plan was transposed onto the phantom. The isocenter was at 5.33-cm depth of water. The gantry angle of each field was reset to 0° while keeping other parameters (e.g. segment shape and MUs) constant. A dose map in the isocenter plane perpendicular to the central beam axis was calculated at the 2 mm×2 mm resolution grid and output as an ASCII file for each field. The plan was transferred to the intended machine via network.

2.3.2 MapCHECK calibration

Calibration of the MapCHECK was performed for each machine at a water equivalent depth of 5.33 cm, which included the inherent depth of 1.35 cm and an additional 3 cm of perspex. To correct for the density difference (the MapCHECK buildup and perspex versus homogeneous water phantom) and for beam divergence, a 95.65 cm source to surface distance (SSD) was set to the top of the perspex plates. The relative dose calibration and absolute dose calibration were performed. The relative dose calibration was performed every half year, while the absolute calibration was done every time just before the verification measurements. The calibration method provided by the manufacturer was adopted.

2.3.3 Dose mapping

After calibration, the fields in the plan were delivered one by one. The measured dose map was saved separately for each field. This allowed a more comprehensive analysis for a better understanding of the error sources in the planning and delivery processes.

2.3.4 Dose map comparison

For each treatment field, the dose map output from TPS was compared to the measured one by MapCHECK software. Both were normalized to the same point chosen in the high dose and low dose gradient region. Agreement between the measured and the calculated relative dose maps was evaluated by determining the percentage of diodes passing a specific acceptance criterion (i.e. passing rate). Only those diodes with relative dose of over 10% were taken into consideration. The acceptance criterion consisted of percent difference (%Diff) and distance to agreement (DTA) criteria. The passing rates were recorded when the acceptance criterion were 2%/2 mm, 3%/3 mm, or 4%/4mm.

2.4 Analysis of passing rate data

In order to find the factors that may affect the passing rate in IMRT verification, the treatment site, treatment machine and optimization mode in planning were considered in statistical analysis. We tested normality of the passing rate data for each acceptance criterion. With a normal distribution of data, a Student t-test or a variance analysis would be conduct, whereas a nonparametric test would be conducted if the data was in skew distribution. SPSS statistic software was used and differences were considered significant at $P < 0.05$.

3 Results

The normality test showed that the passing rate data were in skew distributions. The median passing rate of total 14540 fields was 93.5%, 98.8%, and 100% when the acceptance criterion was 2%/2mm, 3%/3mm and 4%/4mm, and the interquartile range were 11.1%, 3.8% , and 1.3%, respectively.

Benjamin *et al.*[7] found that the combined 3% and 3 mm criteria was the most prevalent criteria for

dose map verification in clinic. Therefore, only the data with 3%/3 mm criteria were analyzed in more detail, considering the treatment site, treatment machine and optimization mode as potential influence factors. Table 1 lists the descriptive statistics of the data. Some combinations of the three factors are blank. One reason for that is the DMPO mode was used just after January 2005. Another reason is we mainly used the Varian600CD and Elekta Synergy for IMRT cases after their commissioning in 2006, instead of the Siemens Primus and Elekta Precise.

Table 1 the statistic data of total 14540 fields with 3%/3mm criteria in each sub-group

		Multiple-step			DMPO		
		Head and neck	Thoracic	Abdominal and pelvic	Head and neck	Thoracic	Abdominal and pelvic
Elekta precise	*m*	92.6	–	92.9	94.5	94.2	94.3
	r	8.17	–	8	5.8	4.7	5.1
	n	544	–	130	719	93	532
Elekta synergy	*m*	–	–	–	99.2	99.4	99.1
	r	–	–	–	2	1.95	2.1
	n	–	–	–	751	280	511
Siemens primus	*m*	87.2	–	77	–	–	–
	r	14.27	–	18	–	–	–
	n	27	—	110	–	–	–
Varian 600CD	*m*	–	–	–	98.9	99.4	99.4
	r	–	–	–	3	2.1	2.1
	n	–	–	–	5556	595	4692

Note: *m*, *r*, and *n* are median, interquartile range, and beam number for short, respectively.

To analyze effect of the above-mentioned factors, we used independent samples test to compare sub-groups. The beam number of thoracic sub-group was smaller than the head and neck sub-group and abdominal and pelvic sub-group. Considering that the median and interquartile range of thoracic sub-group and those of abdominal and pelvic sub-group were almost the same, we combined them into one sub-group in comparing the effect of different treatment sites or different treatment machines. Also we did not consider the Siemens Primus sub-group because of the small beam number.

Factors of the sub-groups were compared one after another, by keeping, the other factors unchanged in the comparison. For example, for the optimization modes, the comparison sub-groups included the multiple-step mode for head and neck site by the Elekta Precise linac sub-group with DMPO mode for head and neck site by the Elekta Precise linac sub-group, or multiple-step mode for abdominal and pelvic site by the Elekta Precise linac sub-group with DMPO mode for abdominal and pelvic site by the Elekta Precise linac sub-group. Seven comparison groups were performed and the results were listed in Table 2. Difference among different treatment sites was not statistically significant ($P>0.05$). Significant differences ($P<0.01$), however, were found in different optimization modes and different linacs. The DMPO mode was significantly better than the multiple-step mode. The rate of passed beams performed in the Elekta Synergy was significantly higher than that performed in the Varian 600CD, and the rate of passed beams performed in the Varian 600CD was significantly higher than that performed in the Elekta Precise.

Table 2 the statistic results of subgroups comparison.

Compared subgroups	*P*
Multiple-step mode for Head and neck site by Elekta Precise linac *vs.* *DMPO mode* for Head and neck site by Elekta Precise linac	<0.001
Multiple-step mode for Abdominal and pelvic site by Elekta Precise linac *vs.* *DMPO mode* for Abdominal and pelvic site by Elekta Precise linac	<0.001
DMPO mode for *Head and neck site* by Elekta Precise linac linac *vs.* DMPO mode for *Abdominal and pelvic(/ Thoracic) site* by Elekta Precise linac	0.776
DMPO mode for *Head and neck site* by Elekta Synergy linac *vs.* DMPO mode for *Abdominal and pelvic(& Thoracic) site* by Elekta Synergy linac	0.232
DMPO mode for *Head and neck site* by Varian 600CD linac *vs.* DMPO mode for *Abdominal and pelvic(& Thoracic) site* by Varian 600CD linac	0.350
DMPO mode for Head and neck site by *Elekta Precise linac vs.* DMPO mode for Head and neck site by *Elekta Synergy linac vs.* DMPO mode for Head and neck site by *Varian 600CD linac*	<0.001
DMPO mode for Abdominal and pelvic(& Thoracic) site by *Elekta Precise linac vs.* DMPO mode for Abdominal and pelvic(& Thoracic) site by *Elekta Synergy linac vs.* DMPO mode for Abdominal and pelvic(& Thoracic) site by *Varian 600CD linac*	<0.001

Note: The considered factor in comparison subgroup is in italics.

4 Discussion and conclusions

In this study we investigated the results of dose map verification of IMRT fields in an attempt to find the factors influencing the dosimetry accuracy of IMRT plans. The differences between the planned and measured dose maps can be attributed to three error sources: dosimeter, delivery system and dose calculation system[8]. If the dosimeter is properly chosen, commissioned and maintained, error is mainly related to calculation, delivery, or a combination of the two. So dose map verification helps us to find problems in calculation and/or treatment delivery. And when an error overruns the clinical tolerance, the source must be find.

Errors in delivery system obviously affect the result of IMRT verification, and we could find it easily. In January 2005 we found in the measured dose maps that the higher dose points were on the right side and the lower dose points were on the left side in comparison with the calculated dose maps. But this phenomenon disappeared by shifting the measured dose maps 2 mm to the left side, and the point passing rate increased. We then checked the machine MLC (multi-leaf collimators) and confirmed about 2 mm error in the MLC movement. After recalibrating the MLC, the results of IMRT verification were improved.

The three factors that we analyzed here were from dose calculation system. In this study, treatment delivery conditions were almost the same to all the treatment plans. The error in treatment delivery was not taken into consideration because we would eliminate the data in our statistics if we found something wrong in course of treatment delivery.

The significant differences in different optimization mode and different treatment linacs can be analyzed as follows. The main difference between the multiple-step and DMPO modes is the number of segments created after optimization[9]. The DMPO mode can complete the optimization in one step, hence the reduced number of segments without sacrificing plan quality. The multiple- step mode can reduce the segments through optimizing segment weight, but the number of segments created in this mode is still much more than the number of segments in DMPO mode. Fewer numbers of segments in a plan means segments with larger area and/or more MUs. That helps improve the dose calculation and delivery accuracy.

The difference among the linacs in TPS was beam modeling. Our lack of experience at the beginning of implementing IMRT technique with the earlier systems (Siemens Primus and Elekta Precise) might accompanied with not-so-reasonable parameters in beam modeling. That may account for the fact that the results with the earlier systems were worse than the new systems (Varian600CD and Elekta Synergy). This situation has been improved when we became experienced gradually in configuring the beam

modeling parameters with the new systems. Although the hardware configuration of the Elekta Synergy is almost the same as the Elekta Precise, except the IGRT (Image guided radiation therapy) capability, the results of the Elekta Synergy, our newest machine, are the best.

The difference among treatment sites is not statistically significant. This is different from that of Ref.[8], in which the percentage of passing points for prostate and other localization cases was significantly higher than that for head and neck cases. This may be explained by the fact that tumor occurrence's distribution varies in different countries. The head-and-neck subgroup in this study includes complex cases, such as nasopharyngeal carcinoma, and simple cases, such as encephaloma. The other subgroups are of cases that had complicated target shapes and were located nearby critical structures such as lymphoma cases.

In conclusion, the beam modeling in TPS is a key point in improving the passing rate of IMRT verification without considering the error in treatment delivery. More reasonable parameters lead to more accurate dose calculation. The factors, the total number of segments, minimum area of segments and minimum MU of segments, also affect the dosimetry accuracy of IMRT plan verification.

Acknowledgements

We thank M.D. CHEN Xinyuan and M.D. HU Zhihui from Cancer Hospital, Chinese Academy of Medical Science, M.D. HE Zhengzhong from Cancer Hospital of HuBei Province, and M.D. DU Decheng from People's Hospital Affiliated to Inner Mongolia Medical College, for their helps in medical physics.

References

1 Bucciolini M, Buonamici F B, Casati M. Med Phys, 2004, **31**(1): 161-168.

2 Jursinic P A, Nelms B E. Med Phys, 2003, **30**(5): 870-879.

3 Létourneau D, Gulam M, Yan D, *et al*. Radiother Oncol, 2004, **70**(2): 199-206.

4 Cilla S, Viola P, Azario L, *et al*. J Appl Clin Med Phys, 2006, **7**(3): 65-79.

5 Talamonti C, Casati M, Bucciolini M. Med Phys, 2006, **33**(11): 4367-4378.

6 Sun Nuclear Corp. MapCHECK Model 1175 Manual. 2004.

7 Nelms B E, Simon J A. J Appl Clin Med Phys, 2007, **8**(3): 2448.

8 Both S, Alecu I M, Stan A R, *et al*. J Appl Clin Med Phys, 2007, **8**(2): 1-8.

9 Jones S, Williams M. Med Dosim, 2008, **33**(1): 86-92.