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Patient delivery quality assurance for linac-based IMRT and helical tomotherapy using solid state detectors

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ABSTRACT

The purpose of this study is to demonstrate how to perform and define appropriate action levels for the intensity-modulated radiation therapy (IMRT) delivery quality assurance (DQA) for both linear accelerator (linac) and helical tomotherapy (HT) plans using a 2D array diode detector. MapCHECK (Sun Nuclear, Melbourne, FL, USA) was used to perform the DQA measurements of patient plans at various sites: brain, head and neck, chest, abdomen, pelvis, spine, bone and others. The measured and planned doses were compared using gamma analysis with a total dose discrepancy of 3% or a gradient difference of 3 mm criteria. DQAs for 507 HT and 380 linac-based IMRT plans were performed, and the mean diode percentage passing rates for 3%/3 mm criteria were 93.8% and 95.1% respectively. For HT delivery, 4.6% and 9.5% of the plans had the passing rates below 80% and 85%, while for linac-based IMRT, 7.4% of the plans had the passing rates lower than 90%. Applying confidence limit with multiplier of 1, action levels for passing rates of 87% and 90% are recommended for HT and IMRT plans respectively.

1. Introduction

Intensity-modulated radiation therapy (IMRT) is widely used to obtain a highly conformal dose distribution to the target while minimizing the dose to the adjacent normal tissues, with multiple subfields modulated by the multileaf collimator (MLC). Quality assurance (QA) for IMRT is very important in terms of patient delivery safety (Ezzell et al., 2009 and Langen et al., 2010). Delivery quality assurance (DQA) for each patient plan becomes more important to improve patient safety.

While ion chambers and films have been widely used to perform the DQA measurements, various new devices have been developed, such as diode or ion chamber arrays, electrical portal imaging device (EPID) and independent monitor units check software to verify the absolute and relative dose of IMRT plans. Although these latest detectors and phantoms provide fast and efficient ways to perform the DQA, there are few reports on how to determine the action levels based on passing rates measured by these devices.

In this study, IMRT DQA for both linear accelerator and helical tomotherapy (HT) plans using a 2D array diode detector were performed. In combination with the statistical results of patients DQA collected within 17 months, we demonstrated how to define appropriate action levels for static and rotational IMRT DQA.

2. Materials and methods

The step-and-shoot IMRT plans were generated within the Pinnacle (Version 7.4, Philips Medical Systems, Cleveland, OH, USA) treatment planning system (TPS) and delivered on a Siemens Mevatron Primus linear accelerator using 5 to 9 beams with 6 and 10 MV energies. The HT plans were performed and delivered using the TPS and operator station of the HT (Hi-ART TomoTherapy, Version 3.2, Tomotherapy Inc, Madison, Wisconsin, USA). The 3D dose-grid size for IMRT and HT plans were $1.5 \times 1.5 \times 1.5$ and $2 \times 2 \times 2$ mm, respectively. All the plans were reviewed and clinically approved by radiation oncologists for treatment. From June 2008 to October 2009, a total of 887 DQA plans were performed, in which 380 plans were delivered using step-and-shoot IMRT linac and 507 plans were delivered using HT.

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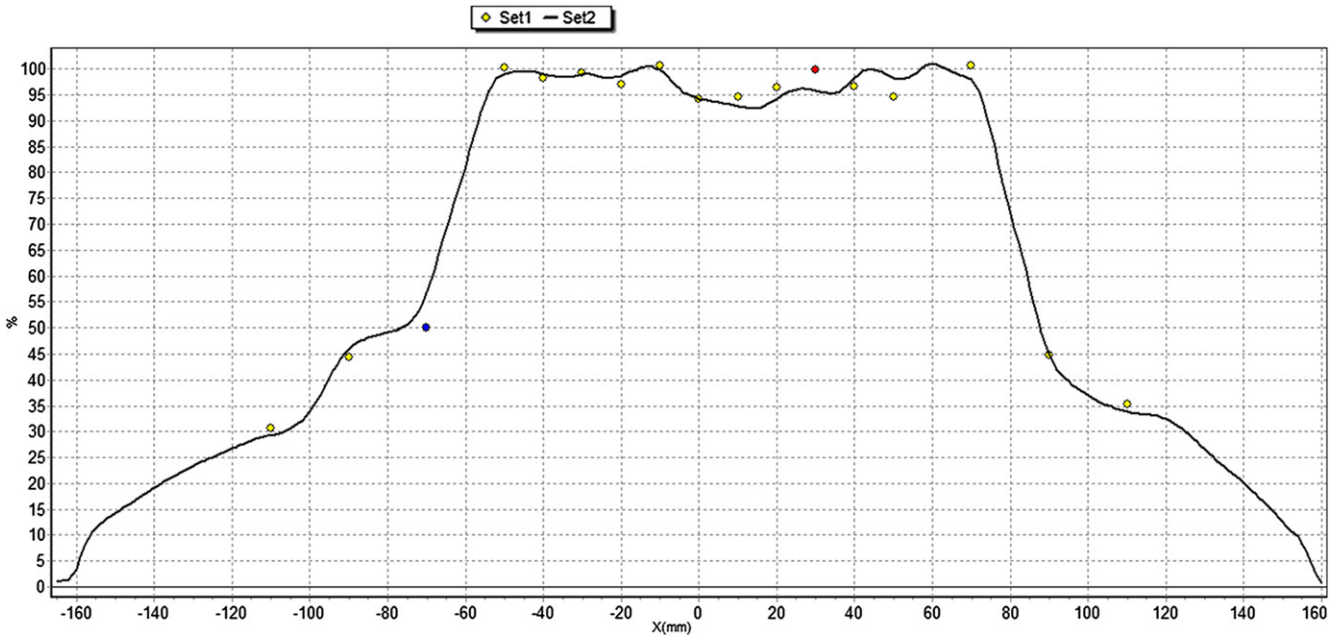

Fig. 1. The dose distribution for one IMRT plans (line) was matched to the measured results (open dots). The solid dots represents the measured data failed the 3%/3 mm criteria.

To generate the DQA geometry for IMRT plans, the intended IMRT plan was re-planned under "QA mode" on the treatment planning system, where the beam geometry of the patient was replaced by a computed tomography scan of a solid water phantom (MapPhan, Sun Nuclear, Melbourne, FL, USA). MapCHECK detector (MapCHECK, Sun Nuclear, Melbourne, FL, USA) was mounted into the MapPhan. The detector contains 445 n-type diodes distributed over an area of 22 × 22 cm. The diode spacing is 7.07 mm in the 10 × 10 cm central portion of the detector and 14.14 mm outside of this area. The active detector area is 0.8 × 0.8 mm for each diode. MapCHECK can perform absolute and relative measurements.

To evaluate the effects of different sites on the results, all the HT cases were divided into 7 sites: brain, head and neck, chest, abdomen, pelvis, spine, bone and other sites, which cannot be divided such as craniospinal irradiation. While the DQA was performed, the gantry angles and collimator angles from each beam were the same as the IMRT plan. The delivered dose per fraction were scaled down to be less than 3.3 Gy under "QA mode" if the dose per fraction was larger than that, as suggested by MapCHECK operational manual.

The calculated and measured doses were compared using MapCHECK software (Version 1.0), under the "relative dose" mode. Diode readings less than 10% were ignored in the analysis. For comparison, the gamma analysis method (Low et al., 1998) was applied with a total dose discrepancy of 3% or a distance to agreement (DTA) of 3 mm tolerance. Using the auto-normalization function in MapCHECK, results of 7 different normalization points including maximum point, point at central dose axis, and five other points showing the best passing rates were displayed. Only the highest passing rate for each composite plan were recorded and applied in defining the action levels of future measurements.

In the statistical analysis, mean and standard deviation were calculated as summaries of continuous variables. Comparisons were performed with Student's *t*-test for continuous variables to detect a difference in mean passing rates with a two-sided alpha level of 0.05. Mean passing rates for different sites were tested individually with overall results.

3. Results and discussion

Fig. 1 shows an example of comparing the planned and measured isodose line by MapCHECK software. The dots were the MapCHECK measured results within 3%/3 mm tolerance and the line was the dose profile calculated from the TPS. The open and solid dots showed that the measured data satisfied and failed the 3%/3 mm criteria, respectively.

Tables 1 and 2 show a summary of gamma passing rates between MapCHECK and the HT plans. The overall mean and median diode percentage passing rates for 3%/3 mm criteria were 93.8% and 95.9%, respectively. The DQA results for the brain and pelvic regions had higher mean passing rates compared to all HT

Table 1
The gamma passing rates for 3%/3 mm criteria for tomotherapy plans.

Sites	Number of study	Mean ± SD[a] (%)	Median (%)	Range (%)	*p* value	Recommended Passing Rates
Brain	37	96.6 ± 4.0	97.8	85.9–100	<0.001	92%
Head and neck	122	93.0 ± 6.5	94.2	62.1–100	0.216	87%
Chest	109	93.9 ± 6.5	96.0	67.0–100	0.796	87%
Abdomen	34	93.5 ± 6.8	95.8	74.0–100	0.776	87%
Pelvis	105	95.0 ± 5.1	96.5	72.4–100	0.040	90%
Spine	37	90.5 ± 10.1	94.5	59.6–100	0.059	87%
Bone	53	93.6 ± 5.6	95.0	72.2–100	0.871	87%
Others	10	92.6 ± 7.9	96.0	77.8–99.2	0.666	87%
Overall	507	93.8 ± 6.5	95.9	62.1–100	–	87%

[a] SD: standard deviation.

Table 2
Gamma analysis results for 507 tomotherapy plans.

Passing Rate	Number of plan	Percentage
50–60%	1	0.2%
60–70%	4	0.8%
70–80%	18	3.6%
80–85%	29	4.9%
85–90%	44	8.7%
90–100%	415	81.9%

Table 3
The gamma passing rates for 3%/3 mm criteria for linac-based IMRT plans.

Sites	Number of study	Mean ± SD[a] (%)	Median (%)	Range (%)	*p* value	Recommended Passing Rates
Brain	15	94.7 ± 6.8	98.1	78.5–99.6	0.620	90%
Head and neck	150	94.5 ± 3.1	94.9	84.9–100	0.071	90%
Chest	102	95.4 ± 3.9	96.5	79.9–100	0.372	90%
Abdomen	6	96.3 ± 3.6	97.3	89.5–99.4	0.899	90%
Pelvis	85	96.8 ± 1.9	97.8	87.2–100	<0.001	95%
Spine	16	96.1 ± 9.7	99.1	60.0–100	0.706	90%
Bone	3	94.4 ± 4.6	96.8	89.1–97.2	NA[b]	90%
Others	3	99.6 ± 0.3	99.5	99.4–100	NA[b]	90%
Overall	380	95.1 ± 4.7	96.2	60.0–100	–	90%

[a] SD: standard deviation.
[b] NA: Not applicable for too small sample size.

plans ($p < 0.05$), whereas other sites showed no significant difference. There are 23 HT DQA plans (4.6%) had the passing rates below 80% and 52 plans (9.5%) had the passing rates lower than 85%.

The gamma analysis for IMRT plans using linac is shown in Tables 3 and 4. The overall mean and median diode percentage passing rates for 3%/3 mm criteria were 95.1% and 96.2%, respectively. Twenty seven plans (7.4%) of linac plans had the passing rates lower than 90%. The results from pelvic region had higher mean passing rates compared to overall linac-based DQA results ($p < 0.001$). There is no significant differences for other sites. In Table 3, the *p* values were not applied to bone and other sites due to small sample sizes.

The American Association of Physicists in Medicine Task Group (AAPM TG) report 119 recommended applying confidence limit with multiplier of 1.96 or smaller for defining the final action levels (Ezzell et al., 2009). In this study, multiplier of 1 was used to meet higher requirement where only 67% of plans will pass the action levels (Tables 1 and 3). For HT plans, the action levels for all sites are recommended to be 87%, and higher passing rates of 92% and 95% can be applied to brain and pelvic regions (Table 1). For linac plans, the recommended overall action level is 90% (Table 3). As pelvic region showed a significant higher passing rates levels, the action levels can be set to 95%.

AAPM TG report 119 recommended action levels in terms of percentage of points passing gamma criteria of 3%/3 mm for linac-based IMRT plans to be is 88–90% for composite irradiations (Ezzell et al., 2009). AAPM TG report 148 (Langen et al., 2010) recommended 90% passing rate for HT DQA plans, analyzed with radiographic film. However, several studies showed that the complexity of the plans at different sites results in a variation of the quality assurance results. Both et al. (2007) showed at 3%/3 mm criteria, 95% passing points and 3% percent dose error can be achieved for prostate treatments and 90% passing points and 5% percent dose error are attainable for any treatment site. Basran and Woo (2008) showed at 3%/3 mm criteria, 95% passing points for non head-and-neck linac-based IMRT cases 88% for head-and-neck linac-based IMRT cases.

The gamma analysis results of the IMRT plans were better than the HT plans, as shown in Tables 1 and 3. One of the reasons is that the beam angles for IMRT selection did not include the 90 and 270°,

Table 4
Gamma analysis results for 380 linac-based IMRT plans.

Passing Rates	Number of plan	Percentage
50–60%	0	0.0%
60–70%	1	0.3%
70–80%	2	0.5%
80–90%	25	6.6%
90–100%	352	92.6%

which were insensitive for MapCHECK measurements due to the electronic design of the MapCHECK (Jursinic et al., 2010). Another reason is plans with large dose falloff gradients or containing multi-targets have lower gamma passing rates (<80%) due to the complexity of plans. For example, some spine cases had a high priority in sparing the spinal cord, which resulted in a very high dose gradient. For the chest and other cases, the passing rates were lower for the plans with large dose gradients falloff or multiple treatment targets. Consequently, there is a higher tendency for these regions exceeding 3%/3 mm criteria.

For the DQA plans with passing rates lower than 80%, the plans were repeated with another delivery procedure of by selecting a different plane of dose for comparison. Eighty percent of the plans passed with repeated measurements or plans. However, 20% of the repeated plans were not improved, mostly of which were head-and-neck plans or with multiple targets. For these plans, the locations of dose points which did not pass the chosen criteria were identified. If these points were located in the penumbra or high dose gradient regions, the plans were accepted for treatment.

4. Conclusion

A number of 887 patient-specific DQAs (380 on linac and 507 on HT) were performed on MapCHECK. Based on the statistical passing rates results of these DQAs, action levels of 90% and 87% is recommended for IMRT and HT plans respectively.

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