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Gamma Evaluation with Portal Dosimetry for Volumetric Modulated Arc Therapy and Intensity-Modulated Radiation Therapy

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The aim of this study is to investigate the characteristics of portal dosimetry in comparison with the MapCHECK2 measurments. In this study, a total of 65 treatment plans including both volumetric modulated arc therapy (VMAT) and intensity-modulated radiation therapy (IMRT) were retrospectively selected and analyzed (45 VMAT plans and 20 IMRT plans). A total of 4 types of linac models (VitalBeam, Trilogy, Clinac 21EXS, and Clianc iX) were used for the comparison between portal dosimetry and the MapCHECK2 measurements. The VMAT plans were delivered with two VitalBeam linacs (VitalBeam1 and VitalBeam2) and one Trilogy while the IMRT plans were delivered with one Clinac 21EXS and one Clinacl iX. The global gamma passing rates of portal dosimetry and the MapCHECK2 measurements were analyzed with a gamma criterion of 3%/3 mm for IMRT while those were analyzed with a gamma criterion of 2%/2 mm for VMAT. Spearman's correlation coefficients (r) were calculated between the gamma passing rates of portal dosimetry and those of the MapCHECK2 measurements. For VMAT, the gamma passing rates of portal dosimetry with the VitalBeam1, VitalBeam2, and Trilogy were 97.3%±3.5%, 97.1%±3.4%, and 97.5%±1.9%, respectively. Those of the MapCHECK2 measurements were 96.8%±2.5%, 96.3%±2.7%, and 97.4%±1.3%, respectively. For IMRT, the gamma passing rates of portal dosimetry with Clinac 21EXS and Clinac iX were 99.7%±0.3% and 99.8%±0.2%, respectively. Those of the MapCHECK2 measurements were 96.5%±3.3% and 97.7%±3.2%, respectively. Except for the result with the Trilogy, no correlations were observed between the gamma passing rates of portal dosimetry and those of the MapCHECK2 measurements. Therefore, both the MapCHECK2 measurements and portal dosimetry can be used as an alternative to each other for patient-specific QA for both IMRT and VMAT.

Keywords: Volumetric modulated arc therapy, Intensity modulated radiation therapy, Gamma analysis, Portal dosimetry

Introduction

Intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) can deliver optimal dose distributions delivering prescription doses to the target volumes, which are enough to control tumor cells, while reducing doses to normal tissues by modulating photon beam intensities.[1-3] IMRT modulates

the photon beam intensities by varying the multi-leaf collimator (MLC) positions while VMAT modulates the photon beams by modulations of MLC positions, gantry rotation speeds, and dose-rates simultaneously during rotations of gantry around a patient.[4,5] By virtue of these capability of IMRT and VMAT to deliver the superior dose distributions to those of the conventional 3D conformal radiation therapy (3D-CRT) technique, IMRT and VMAT have been adopted in the clinic rapidly and widely.[6] However, the planning process of IMRT and VMAT are not intuitive, which is an inverse planning with optimization algorithms, and the delivery mechanisms of IMRT and VMAT are complex involving various mechanical parameters.[4,5] Moreover, calculations of the small or irregular fields which are frequently used for both IMRT and VMAT are not accurate even with the state-of-the-art dose calculation algorithms.[7,8] Therefore, there is potential for both IMRT and VMAT to cause differences between the calculated dose distribution and the actually delivered dose distribution to a patient.[3] This can result in unintended treatment which is detrimental to patients, which should be avoided. In this respect, patient-specific quality assurance (QA) for every patient treated with IMRT or VMAT technique is performed in the clinic before patient treatment.[9-11]

As a patient-specific QA for IMRT or VMAT, 2D gamma evaluation is widely adopted in the clinic.[12] The 2D gamma evaluation can be performed with measured doses by 2D dosimeters placed on the treatment couch or it can be performed with fluences measured with a detector placed orthogonal to the central axis (CAX).[3,9-11,13,14] Portal dosimetry is one of the methods evaluating measured fluences using electronic portal imaging device (EPID) which is attached to the linac.[13,14] Sharma et al. validated the portal dosimetry for IMRT in comparison with the results using 2D ion chamber array with 14 IMRT cases.[14] They concluded both 2D ion chamber array and the portal dosimetry showed comparable results, therefore, both can be used for the patient-specific QA of IMRT. Fogliata et al. validated the VMAT technique with portal dosimetry by utilizing a total of 275 patient cases.[13] They performed gamma evaluation with a gamma criterion of 3%/3 mm for RapidArc plans and showed average gamma passing rate of 99.2±0.2%. Various studies performed on the portal dosimetry, however, no study has been performed on portal dosimetry by utilizing various types of linac models.[13-18] Therefore, in this study, we analyzed the gamma passing rates acquired with portal dosimetry of various types of linac models for both IMRT and VMAT. We compared the gamma passing rates with portal dosimetry to those acquired with a 2D dosimeter, the MapCHECK2™ (Sun Nuclear Corp., Melbourne, Melbourne, FL, USA) in this study.

Materials and Methods

1. Generation of treatment plans

For this study, IMRT and VMAT plans which were already used for patient treatment were retrospectively selected. A total of 65 treatment plans were analyzed in this study (45 VMAT plans and 20 IMRT plans). The treatment sites were various, which were brain, head and neck (H&N), prostate, lung, cervix, breast, liver, and spine. For VMAT planning, two VitalBeam™ with Millennium 120™ MLC (VitalBeam1 and VitalBeam2) and one Trilogy™ with Millennium 120 MLC (Varian Medical Systems, Palo Alto, CA, USA) were used. According to the treatment sites, 6 MV, 10 MV, and 15 MV photon beams were used. A total of 20 VMAT plans, 15 VMAT plans, and 10 VMAT plans were generated with the VitalBeam1, VitalBeam2, and Trilogy, respectively. For IMRT planning, one Clinac iX™ (iX) with the Millennium 120 MLC and one Clinac 21EXS™ (21EXS) with the Millennium 120 MLC (Varian Medical Systems, Palo Alto, CA, USA) were used. In the case of IMRT, 6 MV and 10 MV photon beams were used. The treatment sites of IMRT were brain, H&N, prostate and breast. A total of 10 IMRT plans were generated with the iX and 21EXS, respectively.

2. Measurements

The verification plans for portal dosimetry were generated following the manufacture protocol (Varian Medical Systems, Palo Alto, CA, USA). The source to image distance (SID) was kept to be 100 cm when performing portal dosimetry. In order to verify portal dosimetry, independent verification of each plan was performed with the MapCHECK2 dosimeter combined with the MapPHAN™ (Sun Nuclear

Corp., Melbourne, FL, USA). Before portal dosimetry, EPID positioning calibration as well as imaging calibration were performed. In the case of MapCHECK2, array calibration according to the manufacturer protocol were performed before the patient-specific QA.

3. Data analysis

Global gamma analysis was performed for both portal dosimetry and the MapCHECK2 measurements. The threshold value was 10%, i.e. doses less than 10% of the maximum dose were ignored during gamma analysis.[11] The gamma criterion for VMAT was 2%/2 mm per the recommendation of previous studies while that for IMRT was 3%/3 mm which is widely adopted in the clinic for patient-specific QA of IMRT.[3,9,10] The statistical significance of the differences between portal dosimetry and the MapCHECK2 measurements was examined with paired t-test. Correlations between the gamma passing rates of portal dosimetry and those of the MapCHECK2 measurements were investigated by calculating the Spearman's correlation coefficients (r).

Results

1. Gamma passing rates of VMAT

The gamma passing rates of portal dosimetry and the MapCHECK2 measurements for VMAT with a gamma criterion of 2%/2 mm are shown in Table 1. For both portal dosimetry and the MapCHECK2 measurements, no distinctive differences were observed among the gamma passing rates of the VitalBeam1, VitalBeam2, and Trilogy. To compare the gamma passing rates of portal dosimetry to those of MapCHECK2 measurements, no statistically significant differences were observed for the VitalBeam1, VitalBeam2, and the Trilogy (all with $p>0.05$). Although there were no statistically significant differences, the gamma passing rates of the portal dosimetry were slightly higher than those of the MapCHECK2 measurements on average. For every case, the average global gamma passing rates were always higher than 96%. For the VitalBeam1 and the VitalBeam2, two VMAT plan showed the gamma passing rates less than 90% (89.1% for both the VitalBeam1 and VitalBeam2), however, those VMAT plans showed higher gamma passing rates than 90% in the case of the MapCHECK2 measurement. For the Trilogy, the gamma passing rates were always higher than 90% for both portal dosimetry and the MapCHECK2 measurements.

Table 1. Gamma passing rates of portal dosimetry and the MapCHECK2 measurements for volumetric modulated arc therapy with a gamma criterion of 2%/2 mm.

Machine	Portal dosimetry	MapCHECK2	p
VitalBeam 1	97.3±3.5 (89.1~100.0)	96.8±2.5 (90.0~100.0)	0.543
VitalBeam 2	97.1±3.4 (89.1~100.0)	96.3±2.7 (90.0~100.0)	0.476
Trilogy	97.5±1.9 (93.9~99.9)	97.4±1.3 (95.3~99.8)	0.876

2. Gamma passing rates of IMRT

The gamma passing rates of portal dosimetry and the MapCHECK2 measurements for IMRT with a gamma criterion of 3%/3 mm are shown in Table 2. For both portal dosimetry and the MapCHECK2 measurements, no distinctive differences were observed between the gamma passing rates of 21EXS and iX. To compare the gamma passing rates of portal dosimetry to those of MapCHECK2 measurements, statistically significant differences were observed with the 21EXS (99.7% for portal dosimetry vs. 96.5% for the MapCHECK2 with $p=0.02$) while no statistically significant differences were observed with the iX ($p=0.076$). The gamma passing rates of the portal dosimetry were higher than those of the MapCHECK2 measurements on average. For every case, the average global gamma passing rates were always higher than 96%. For both the 21EXS and iX, every IMRT plan showed higher gamma passing rates than 90% with both portal dosimetry

Table 2. Gamma passing rates of portal dosimetry and the MapCHECK2 measurements for intensity-modulated radiation therapy with a gamma criterion of 3%/3 mm.

Machine	Portal dosimetry	MapCHECK2	p
Clianc 21EXS	99.7±0.3 (99.0~99.9)	96.5±3.3 (90.7~99.9)	0.020
Clinac iX	99.8±0.2 (99.3~100.0)	97.7±3.2 (91.1~99.3)	0.076

and the MapCHECK2, which means every IMRT plan in this study was clinically acceptable.

3. Correlation analysis

The Spearman's correlation coefficients (r) and corresponding p-values between the gamma passing rates of portal dosimetry and those of the MapCHECK2 measurements are shown in Table 3. For VMAT, statistically significant correlation between the gamma passing rates of portal dosimetry and those with the MapCHECK2 measurements with gamma criterion of 2%/2 mm was observed with the Trilogy (r=0.658 with p=0.038) while no statistically significant correlations were observed for the VitalBeam1 and VitalBeam2. For IMRT, no statistically significant correlations between the gamma passing rates of portal dosimetry and those of MapCHECK2 measurements with a gamma criterion of 3%/3 mm were observed with both the 21EXS and iX (r<0.2 with p>0.05).

Discussion

In this study, we investigated the portal dosimetry results comparing to the MapCHECK2 measurements by utilizing various types of linac models (VitalBeam, Trilogy, Clinac 21EXS, and Clinac iX). Both the gamma passing rates of portal dosimetry and the MapCHECK2 measurements generally showed higher gamma passing rates than 90% which is the tolerance level.[9,10] The average values of gamma passing rates of portal dosimetry were always higher than those of MapCHECK2 measurements, however, the magnitudes of differences were minimal for VMAT, showing differences less than 1% (all with p>0.05). In the case of IMRT, the gamma passing rates of portal dosimetry were always higher than those of the MapCHECK2 measurements showing differences more than 2%. With the 21EXS, statistically significant difference with p value of 0.02 was observed between the gamma passing rates of portal dosimetry and the MapCHECK2 measurements. Although the average values of gamma passing rates of portal dosimetry were higher than those of the MapCHECK2 measurements, the MapCHECK2 measurements showed no gamma passing rates less than 90%, however, the gamma passing rates of portal dosimetry were less than 90% for two cases (two VMAT plans with VitalBeam1 and VitalBeam2). However, the gamma passing rates of the two cases were marginal, which were both 89.1%, showing values close to the tolerance level of 90%. In summary, there were no distinctive differences between portal dosimetry and the MapCHECK2 measurements regardless of the types of linac models although the gamma passing rates of portal dosimetry were slightly higher than those of the MapCHECK2 measurements on average.

Between the gamma passing rates of portal dosimetry and those of the MapCHECK2 measurements, no correlations were generally observed. If unacceptable IMRT or VMAT plans owing to high modulations were included in this study, correlations might be observed between the gamma passing rates of portal dosimetry and those of the MapCHECK2 measurements, however, every IMRT and VMAT plan in this study was not excessively modulated and used for patient treatment with higher gamma passing rates than 90% with the MapCHECK2 measurements. Since the variation of the modulation degrees of the analyzed plans was small in this study, the correlations between portal dosimetry and the MapCHECK2 measurements might not be observed. By utilizing more treatment plans, further study on the correlation between portal dosimetry and the measurement of the 2D planar dose distribution will be performed in the future.

Table 3. Correlations between the gamma passing rates of portal dosimetry and those of MapCHECK2 measurements.

Technique	Machine	Gamma criterion	N	r	p
VMAT	VitalBeam 1	2%/2 mm	20	0.381	0.097
	VitalBeam 2		15	0.221	0.429
	Trilogy		10	0.658	0.038
IMRT	21EXS	3%/3 mm	10	–0.075	0.836
	iX		10	0.107	0.769

VMAT: volumetric modulated arc therapy, IMRT: intensity-modulated radiation therapy, N: number, r: Spearman's correlation coefficient.

Conclusion

The gamma passing rates of portal dosimetry were comparable to those of the MapCHECK2 measurements for both IMRT and VMAT. No distinctive differences were observed among various types of linac models. Therefore, both the MapCHECK2 measurements and portal dosimetry can be used as an alternative to each other for patient-specific QA of both IMRT and VMAT.

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Conflicts of Interest

The authors have nothing to disclose.

Availability of Data and Materials

All relevant data are within the paper and its Supporting Information files.

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