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Investigation of Error Detection Capabilities of Various Patient-Specific Intensity Modulated Radiotherapy Quality Assurance Devices

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Abstract

The capability of error detection of patient-specific QA tools plays an important role in verifying MLC motion accuracy. The goal of this study was to investigate the capability in error detection of portal dosimetry, MapCHECK2 and MatriXX QA tools in IMRT plans. The 9 fields IMRT for 4 head and neck plans and 7 fields IMRT for 4 prostate plans were selected for the error detection of QA devices. The measurements were undertaken for the original plan and the modified plans, where the known errors were introduced for increasing and decreasing of prescribed dose (±2%, ±4% and ±6%) and position shifted in X-axis and Y-axis (±1, ±2, ±3 and ±5 mm). After measurement, the results were compared between calculated and measured values using gamma analysis at 3%/3 mm criteria. The average gamma pass for no errors introduced in head and neck plans was 96.9%, 98.6%, and 98.8%, while prostate plans presented 99.4%, 99.0%, and 99.7%, for portal dosimetry, MapCHECK2 and MatriXX system, respectively. In head and neck plan, the shifted error detections were 1 mm for portal dosimetry, 2 mm for MapCHECK2, and 3 mm for MatriXX system. In prostate plan, the shifted error detections were 2 mm for portal dosimetry, 3 mm for MapCHECK2, and 5 mm for MatriXX system. For the dose error detection, the portal dosimetry system could detect at 2% dose deviation in head and neck and 4% in prostate plans, while other two devices could detect at 4% dose deviation in both head and neck and prostate plans. Portal dosimetry shows slightly more capability to detect the error compared with MapCHECK2 and MatriXX system, especially in the complicated plan. It may be due to higher resolution of the detector; however, all three-detector types can detect various errors and can be used for patient-specific IMRT QA.

Keywords

Error Detection, Gamma Analysis, IMRT Plan, Intentional Errors, QA Tool

1. Introduction

Intensity modulated radiation therapy (IMRT) technique is one of the advanced radiation treatment techniques, which allows conformal shaping of dose distribution to tumors and significantly gains in the sparing of normal surrounding tissues. IMRT achieves desired dose distribution in a complex shaped volume by modulating the intensity map of each treatment field using the moving of multileaf collimator (MLC). So, the position of MLC pattern needs to be verified as the patient-specific quality assurance (QA) for all IMRT plans before deliver dose to patients [1]. There are many methods to verify the patient-specific IMRT plan, such as point dose, planar dose and volume dose verification types. The most common QA devices used for this scenario are planar dosimeters, such as films, diode arrays, ionization chamber arrays and electronic portal imaging devices (EPID). The example of diode array is MapCHECK2 that provides the small size of diode detector (0.000019 cm^3) and is arranged in 2D array. The ionization chamber uses the principle of air ionized after received radiation. The example of 2D ionization array is MatriXX that consists of many vented ionization chambers. Each chamber has 0.08 cm^3 volume with the height of 5 mm and diameter of 4.5 mm. EPID is originally designed for treatment field verification before the treatment; however, it has been applied for dosimetry device as a patient-specific IMRT QA due to the high spatial resolution of amorphous silicon (aSi) diode array. For two-dimensional QA tools, the gamma index that combines dose difference and distance to agreement to the single parameter is routinely used for dosimetric evaluation of treatment plans. According to different designs, configurations and kinds of detectors of QA tools, the capability of each detector is different. The sensitivity of each QA tool depends on the type and number of detectors, arrangement, and spacing among them.

Li *et al.* [2] studied the efficiency of set-up error detection using diode array, ArcCHECK and Delta4 system, with the volumetric modulated arc therapy (VMAT) technique. The applied errors in this study were translation errors of ±1.0 to ±3.0 millimeter (mm) and rotational set-up errors of 1.0 to 2.0 degrees. The combined effect of 2.0 mm translational and 1.0-degree rotational errors was also analyzed. The dose distribution comparison of two systems was analyzed by gamma index with 3.0%/3.0 mm, 3.0%/2.0 mm and 2.0%/2.0 mm criterion. There were 11 VMAT delivered on QA tool each system for dose verification measurements on Elekta Synergy linear accelerator. The measured and calculated dose distributions of each QA tool were compared. For the translation error of ±1.0 to ±3.0 mm in the direction of right-left and superior-inferior showed significant difference in results. The results indicated that ArcCHECK

was higher sensitivity than Delta4 in detection of translational error in both directions. The results of rotational set up error also showed significant different result between two systems. For rotational error of 1.0 to 2.0 degree, gamma passing rate by 3.0%/3.0 mm decreased by 5.5% and 9.9% for ArcCHECK and 2.5% and 5.0% for Delta4 in the pitch direction. ArcCHECK had higher sensitivity in rotational error detection than Delta4. The combined effect of 2.0 mm translational and 1.0 degree rotational error result, ArcCHECK showed 3.4%, 3.1%, 3.3%, 2.9%, and 5.6%, for esophageal, prostate, cervix, rectal, and nasopharyngeal cancer, respectively but the result of Delta4 was slightly lower than ArcCHECK. That's why; ArcCHECK was slightly more sensitive to all type of set up error in this study. Bawazeer *et al.* [3] studied the ability of MatriXX system and electronic portal imaging device (EPID) to detect the systematic delivery errors in IMRT plans. The aim of this work was to investigate the ability of two commercially available QA tools to detect the systematic MLC leaf position and collimator errors. The hypotheses of their study were to detect the smallest significant error and sensitivity of each detector. Two step and shot IMRT plans were used in this study. Same direction and opposite direction shifted MLC errors and collimator errors of one degree to five degree were introduced in the plan for measurement. By using Elekta Synergy linear accelerator the original and applied error plans were delivered. From the results, both systems were lack of ability in detection of smallest significant errors of 1 mm MLC shift and 2-degree collimator rotation. Moreover, both detector systems had similar sensitivity for all types of error except collimator rotation error in head and neck plan. For that kind of error, MatriXX was more sensitive than EPID.

The purpose of this study was to evaluate the error detection sensitivity and capability of patient specific IMRT QA tools of portal dosimetry, MapCHECK2, and MatriXX systems.

2. Materials and Methods

2.1. Creating Intensity Modulated Radiotherapy Plans

There were 8 IMRT plans in this study that consisted of four head and neck and four more prostate plans optimized and calculated according to Radiation Therapy Oncology Group dose constraints protocol using Eclipse treatment planning system Version 11.0.31 (Varian Medical Systems, Palo Alto, CA, USA). The 6 Megavoltage (MV) beams were employed with 9 fields arrangement for head and neck IMRT cases as the complicated plans, while 10 MV beams with 7 fields were optimized and calculated for prostate IMRT plans to represent the simple plans. After radiation oncologist approved the plans, the clinical IMRT plans were converted to IMRT QA verification plans with converting the gantry angle to zero degree orientation for all beams and calculating the dose in water phantom for EPID (Varian Medical Systems, Palo Alto, CA, USA), MapCHECK phantom for MapCHECK2 system (Sun Nuclear Corporation, Melbourne, FL, USA) and MultiCube phantom for MatriXX system (IBA dosimetry, Bartlett,

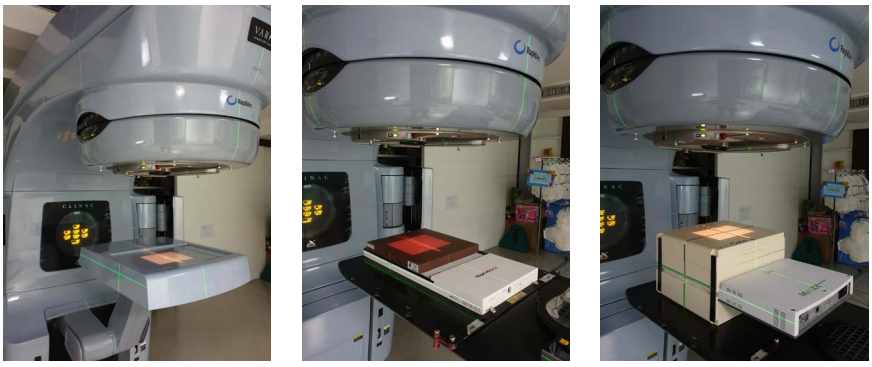
TN, USA). The aS1000 flat panel EPID has the area of 40 × 30 cm^2 with the matrix size of 1024 × 768 pixels. MapCHECK consists of 1527 N-type diodes arranged in 2D array on the size of 32 × 26 cm^2 with 7.07 detector spacing uniform through array. The MatriXX device consists of a 1020 vented parallel plate ionization chamber detectors with a 7.6 mm center-to-center spacing between chambers that arranged in 32 × 32 cm^2 grid area.

2.2. Introducing Intentional Errors

After creating original IMRT QA plans, the intentional error plans were created. All errors introduced were based on the most realistic clinical situations. The intentional errors were composed of prescribed dose errors and position shifts. Prescribed dose of increasing and decreasing from 2.0%, 4.0% to 6.0% and position shift of 1.0, 2.0, 3.0, and 5.0 mm in positive and negative ways in both X- and Y-directions were applied. The errors were created in treatment plan for measurement of error detection. Then, all of the QA plans were exported to linear accelerator machine for delivery in each QA tool.

2.3. Measuring Systems

The original plans and plans with intentional errors were measured on ClinaciX linear accelerator (Varian Medical Systems, Palo Alto, CA, USA) by all QA tools, EPID, MapCHECK2 and MatriXX systems. The EPID, which was fixed with Varian ClinaciX machine, was set at 100.0 centimeter (cm) source to detector distance (SDD) as shown in Figure 1(a). For MapCHECK2 setup, the device was placed on the patient couch and the laser was used to set at the detector depth. The 95.8 cm source to surface distance (SSD) was set and then 3.0 cm solid water phantom was added on MapCHECK2 surface to acquire the 5.0 cm water equivalent thickness as shown in Figure 1(b). In case of MatriXX, it was inserted in MultiCube phantom and placed on treatment couch as shown in Figure 1(c). The lines on the MultiCube phantom were set to coincide with the laser system to represent the detectors position at 100.0 cm SDD. All of the measurement data were saved in respective software for further analysis.



(a) (b) (c)

Figure 1. The measurement setup of (a) portal Dosimetry, (b) MapCHECK2, and (c) MatriXX system.

2.4. Analyzing the Measurements

The gamma evaluation index was recommended to analyze the dose distribution plane between treatment planning system (TPS) calculation and each QA tool measurement. In order to observe the error detection of QA tools, the measurements with intentional errors were compared with the original plans that no any error applied. The Varian portal dosimetry software, SNC patient software, and OmniPro-I'mRT software were used to evaluate using gamma index concept for portal dosimetry, MapCHECK2, and MatriXX, respectively. The gamma index of 3.0% dose difference and 3.0 mm distance to agreement with 10.0% threshold were selected for the evaluation criteria. The gamma-passing rate was set at 95.0% in our routine passing criteria and an error was considered detected when the gamma failure rate was higher than 5.0%. We then analyzed the gamma result of modified plans and evaluated the error detection capability of each QA tool. According to the ethic consideration, this study respect for person authority, principle of beneficence/non-maleficence and justice rule. Although this study does not contact directly to the patients for data collection, the research was approved by Ethics Committee of Faculty of Medicine, Chulalongkorn University.

3. Results

3.1. Original Plans Measurement

The measurements were undertaken by measuring the original plan as the first step using Portal dosimetry, MapCHECK2 and MatriXX systems. Table 1 shows the gamma pass results of original plans measured by three patient-specific QA devices for head and neck, and prostate plans.

3.2. Error Detection by Portal Dosimetry System

After measuring original plans that pass 95.0% gamma result, the plans introduced with 1.0 mm to 5.0 mm shifted in X- and Y-axis errors were measured to evaluate the error detection sensitivity upon position shift of portal dosimetry system using gamma pass criteria of 3.0%/3.0 mm. The smallest error

Table 1. Gamma passing rate results of the original head and neck and prostate plans measured by portal dosimetry, MapCHECK2 and MatriXX systems.

Case No.	Gamma passing rate (%)					
	Portal dosimetry		MapCHECK2		MatriXX	
	H & N	Prostate	H & N	Prostate	H & N	Prostate
1	95.2	99.6	97.9	100.0	97.5	99.8
2	96.6	99.9	98.6	100.0	99.3	99.9
3	98.9	99.8	99.3	96.5	99.7	99.5
4	96.8	98.3	98.3	99.4	98.2	99.8
Average	96.9 ± 1.3	99.4 ± 0.7	98.6 ± 0.6	99.0 ± 1.7	98.8 ± 1.0	99.8 ± 0.2

detections were 1.0 mm shifted in head and neck and 2.0 mm shifted in the prostate plans. Considering to different directions, the error detection in some axis showed error started from 3.0 mm shifted in head and neck plan and 5 mm shifted in the prostate. The detected results of portal dosimetry system in head & neck and prostate plans are shown in Table 2.

Table 3 shows the results of prescribed dose error measured by portal dosimetry system in head and neck and prostate IMRT plans. The prescribed dose errors plans were measured and analyzed by 3.0%/3.0 mm criteria for both head and neck region and prostate region IMRT plans. The prescribed dose of 2.0% increasing and 4.0% decreasing were detected in head and neck plans. In prostate IMRT plans, the error of 4.0% in both increasing and decreasing dose were observed.

Table 2. The average percent gamma pass of position shift errors measured in head and neck and prostate intensity modulated radiotherapy plans using portal dosimetry system.

Position shift error (mm)		Gamma passing rate (%)	
		H & N	Prostate
X-axis	1.0	96.5 ± 1.1	99.4 ± 0.7
	2.0	96.3 ± 1.7	99.1 ± 1.0
	3.0	92.7 ± 1.9	97.9 ± 1.5
	4.0	70.1 ± 5.2	71.3 ± 13.4
X-axis	−1.0	94.5 ± 2.0	99.1 ± 0.9
	−2.0	86.1 ± 2.3	94.2 ± 3.4
	−3.0	73.0 ± 4.7	76.5 ± 12.4
	−4.0	55.9 ± 9.0	60.4 ± 17.6
Y-axis	1.0	94.9 ± 1.9	98.9 ± 1.0
	2.0	87.8 ± 3.4	94.2 ± 3.5
	3.0	82.3 ± 3.2	83.8 ± 4.6
	4.0	74.3 ± 5.9	70.6 ± 4.6
Y-axis	−1.0	96.9 ± 1.4	99.4 ± 0.7
	−2.0	96.6 ± 1.5	99.3 ± 0.9
	−3.0	95.2 ± 1.9	98.4 ± 0.6
	−4.0	83.8 ± 4.3	80.5 ± 2.5

Table 3. The average percent gamma pass of prescribed dose errors measured in head and neck and prostate intensity modulated radiotherapy plans using portal dosimetry system.

Prescribed dose error (%)		Gamma passing rate (%)	
		H & N	Prostate
Increasing	2.0	89.5 ± 2.8	98.6 ± 1.4
	4.0	82.6 ± 3.0	90.9 ± 6.6
	6.0	75.1 ± 4.2	82.8 ± 10.4
Decreasing	−2.0	95.1 ± 4.6	95.7 ± 3.4
	−4.0	93.3 ± 5.7	83.4 ± 12.1
	−6.0	87.3 ± 7.4	73.5 ± 16.1

3.3. Error Detection by MapCHECK2 System

The MapCHECK2 system could detect error starting from −2.0 mm and +3.0 mm in X-axis and +2.0 mm and −3.0 mm in Y-axis for the head neck plan, while the error starting from 3.0 mm in both directions for prostate were detected by MapCHECK2 as shown in Table 4.

Table 5 shows the results of prescribed dose error measured by MapCHECK2 system in head and neck and prostate IMRT plans. The prescribed dose error of 6.0% increasing and 4.0% decreasing were detected in head and neck plans analyzed by 3.0%/3.0 mm criteria. In prostate IMRT plans the error of 4.0% in both increasing and decreasing dose were observed.

Table 4. The average percent gamma pass of position shift errors measured in head and neck and prostate intensity modulated radiotherapy plans using MapCHECK2 system.

Position shift error (mm)		Gamma passing rate (%)	
		H & N	Prostate
X-axis	1.0	98.6 ± 0.7	98.8 ± 1.7
	2.0	98.0 ± 1.0	98.2 ± 2.0
	3.0	93.4 ± 2.9	92.9 ± 3.7
	4.0	64.3 ± 6.7	60.8 ± 13
X-axis	−1.0	96.8 ± 1.8	98.8 ± 2.0
	−2.0	91.1 ± 3.1	97.1 ± 3.4
	−3.0	75.7 ± 3.3	84.1 ± 10
	−4.0	49.6 ± 2.4	53.9 ± 19
Y-axis	1.0	97.0 ± 1.7	99.0 ± 1.7
	2.0	92.6 ± 2.6	95.5 ± 4.4
	3.0	87.3 ± 3.7	87.4 ± 5.7
	4.0	75.0 ± 4.3	75.1 ± 11
Y-axis	−1.0	98.5 ± 0.4	98.7 ± 1.5
	−2.0	96.9 ± 0.6	96.9 ± 2.5
	−3.0	93.6 ± 2.2	90.1 ± 5.1
	−4.0	81.1 ± 2.3	68.7 ± 5.7

Table 5. The average percent gamma pass of prescribed dose errors measured in head and neck and prostate intensity modulated radiotherapy plans using MapCHECK2 system.

Prescribed dose error (%)		Gamma passing rate (%)	
		H & N	Prostate
Increasing	2.0	98.1 ± 0.3	98.8 ± 1.0
	4.0	96.0 ± 1.2	91.1 ± 6.0
	6.0	89.3 ± 2.9	82.8 ± 8.1
Decreasing	−2.0	95.4 ± 4.2	95.4 ± 4.9
	−4.0	88.9 ± 8.7	85.3 ± 8.0
	−6.0	80.3 ± 12.2	75.9 ± 5.3

3.4. Error Detection by MatriXX System

The results of position shifted error measured by MatriXX system is shown in Table 6 for head and neck and prostate IMRT plans. The error detection by MatriXX system were started from 3.0 mm shifted and higher magnitude of error in almost all directions for head and neck plans, except Y-positive direction that found at 5.0 mm shifted, while the detected errors were started from 5.0 mm shifted in all directions for the prostate plans.

Table 7 shows the results of prescribed dose error measured by MatriXX system in head and neck and prostate IMRT plans. The prescribed dose errors of 4.0% in both increasing and decreasing were observed in the head and neck plans, while this device could not detect the prescribed dose error even dose change up to 6.0% when analyzing with 3.0%/3.0 mm gamma criteria.

Table 6. The average percent gamma pass of position shift errors measured in head and neck and prostate intensity modulated radiotherapy plans using MatriXX system.

Position shift error (mm)		Gamma passing rate (%)	
		H & N	Prostate
X-axis	1.0	97.4 ± 1.5	99.4 ± 0.4
	2.0	95.1 ± 2.1	98.6 ± 0.5
	3.0	83.3 ± 4.6	96.7 ± 0.9
	4.0	66.8 ± 7.8	92.0 ± 1.2
X-axis	−1.0	98.2 ± 1.4	99.5 ± 0.5
	−2.0	95.5 ± 2.7	99.2 ± 0.7
	−3.0	89.3 ± 5.2	98.1 ± 1.1
	−4.0	72.2 ± 7.1	93.5 ± 1.3
Y-axis	1.0	98.6 ± 1.2	99.7 ± 0.2
	2.0	97.9 ± 1.5	99.0 ± 0.8
	3.0	95.8 ± 1.7	97.6 ± 0.9
	4.0	88.0 ± 2.5	92.8 ± 2.1
Y-axis	−1.0	98.2 ± 1.4	99.7 ± 0.2
	−2.0	96.9 ± 2.1	99.4 ± 0.4
	−3.0	93.9 ± 3.1	98.1 ± 0.9
	−4.0	85.7 ± 4.2	94.1 ± 2.4

Table 7. The average percent gamma pass of prescribed dose errors measured in head and neck and prostate intensity modulated radiotherapy plans using MatriXX system.

Prescribed dose error (%)		Gamma passing rate (%)	
		H & N	Prostate
Increasing	2.0	97.9 ± 1.1	98.9 ± 1.1
	4.0	94.8 ± 1.2	97.4 ± 1.5
	6.0	84.3 ± 6.3	96.0 ± 1.8
Decreasing	−2.0	95.1 ± 3.1	98.8 ± 0.9
	−4.0	85.5 ± 8.1	97.3 ± 1.2
	−6.0	75.6 ± 11.3	95.5 ± 2.1

4. Discussion

4.1. Gamma Passing Rate Results of Original Plans

The percent gamma passing rate of the original head and neck plans using by 3.0%/3.0 mm criterion with 10.0% threshold were 96.9 ± 1.3, 98.6 ± 0.6 and 98.8 ± 1.0 for portal dosimetry system, MapCHECK2 system and MatriXX system, respectively. The results of prostate were 99.4 ± 0.7, 99.0 ± 1.7 and 99.8 ± 0.2 for portal dosimetry system, MapCHECK2 system and MatriXX system, respectively. All of the plans were pass the tolerance limit of 95.0% gamma pass. These results were agreed with the gamma passing rate reported by Son *et al.* [4] who showed the average gamma passing rate results for all organs of 99.6 ± 0.4, 99.0 ± 0.2 and 99.3 ± 0.2 for portal dosimetry system, MapCHECK2 system and MatriXX system, respectively. The average gamma pass of head and neck plans that measured by all devices were lower than the results of prostate because of the complicated plan in irregular shape of head and neck. This was attributed to increase the modulation and field size in head and neck plan [5].

4.2. Position Shifted Error Detection by the Quality Assurance

The 95.0% gamma pass was set as the criteria to determine the error detection ability. The position-shifted errors were applied by shifting in X-axis (lateral direction) and Y-axis (longitudinal direction) with the magnitude of 1.0 mm, 2.0 mm, 3.0 mm and 5.0 mm. For the head and neck IMRT plans, the error detection by the portal dosimetry showed the smallest error detection of 1.0 mm shifted in X-axis (negative direction) and Y-axis (positive direction). At the same condition the error of 2.0 mm and 3.0 mm shifted were detected by MapCHECK2 system and MatriXX system, respectively.

In the prostate plans, the smallest error detection of 2.0 mm shifted can be seen with the portal dosimetry system in X-axis (negative direction) and Y-axis (positive direction). For other directions, the error of 5.0 mm shifted was detected by portal dosimetry. The other two devices, MapCHECK2 system can detect at 3.0 mm shifted with and 5.0 mm shifted with MatriXX system in all directions. For the prostate, the target organ was quite round shape and the error detection in the different direction showed the same magnitude, while the error detection in different direction showed different results in the head and neck plan because of irregular shape of the target volume.

When the error magnitudes increase, the gamma passing results decrease. The decrease in percent gamma pass for 1.0 mm shifted was around 1.0% for all devices. However, when the higher magnitude of error was introduced, the decrease percent gamma result was more different for each device. At 5.0 mm shifted, the average error from all position shifted and in both regions from MapCHECK2 system showed 32.7% gamma pass decreases from the original plan results, whereas portal dosimetry decreased 27.3% gamma pass and MatriXX system was only 13.7% gamma pass reduction. The MatriXX was less sensitive to the more error introduced.

Because of the fine resolution of portal dosimetry system (0.39 × 0.39 mm) compared to the other two devices, small displacement in fluence map of the IMRT plan results the higher drop of the percent gamma pass [6] [7]. Once the error was introduced, the fine detection point of portal dosimetry system could show more deviation of the fluence from the original plan rather than MapCHECK2 system and MatriXX system which had 0.5 cm and 0.7 cm detector spacing, respectively. So, even the same magnitude of shifted, portal dosimetry could find more point of disagreement for original plan and the modified plans. That was the reason the portal dosimetry system could detect the small magnitude of error than the other two QA devices. It was agreed with Sumida *et al.* [8] studied whom suggested that the large target should use a finer resolution detector like portal dosimetry to compensate for the software interpolation data.

4.3. Prescribed Dose Error Detection by Three Devices

Increasing or decreasing of dose from 2.0% to 6.0% was performed to detect the prescribed dose error measurements. The results were not evidently different for the error detection of all devices. These attributes to the response of the dose of all detectors were not significantly different. The 2.0% increasing dose error in head and neck plan was detected by portal dosimetry, while other two devices can detect at 4.0% dose error. In the prostate plan, portal dosimetry system and MapCHECK2 system can find out of 4.0% dose error, while the 6.0% dose error was detected by MatriXX system. The gamma passing rate of three devices showed not significantly drop like in the position shifted error plan.

When the dose error was introduced, the percent gamma was exactly decreased. The higher decreasing of results was seen in portal dosimetry system, which the average passing rate in both increase and decrease in dose error and in both regions was 94.7%, 87.6% and 79.7% for the 2.0%, 4.0% and 6.0% dose errors, respectively. The results of MapCHECK2 system were 96.9%, 90.3% and 82.1% and the results of MatriXX were 97.7%, 93.8% and 87.9%. As the error magnitude was increased, the portal dosimetry system reacted evidently with the rapid change of the percent gamma pass. Bojechko and Ford [9] also found that EPID dosimetry was able to detect relatively small variations in overall dose and systematic shifts.

The introduced of prescribed dose was distributed over all area of the fluence rather than at a single point. Even the measurement over the entire fluence map was same for all devices but fine resolution point could meet all deviation of dose from original plan and modified plans. Once the error was introduced (2.0%, 4.0% and 6.0% prescribed dose increasing or decreasing) the fine detection point of the portal dosimetry system could show more deviation of the fluence from the original plan rather than MapCHECK2 system and MatriXX system. So, even the same magnitude of dose change, the portal dosimetry could find more point of disagreement for original plan and the modified plans. It was the reasons that portal dosimetry system could detect the small magnitude of error than other two QA devices.

5. Conclusion

All the devices perform well in terms of error detection, and error detection of each QA tool depending on the error types, sites, tumor shapes, plan complexities and also gamma criteria used to analyze. Each device has advantages and disadvantages upon its usage. The configurations of QA tools also play an important role in the sensitivity of error detection. The higher the resolution of QA tools, the better the sensitivity of error detection. From the results, it can be concluded that portal dosimetry system has marginally higher sensitivity than MapCHECK2 and MatriXX systems in both shifted positions and dose errors because it has higher resolution of detectors.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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