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A Comparison of Patient-specific Delivery Quality Assurance (DQA) Devices in Radiation Therapy

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방사선치료에서 환자맞춤형 선량품질보증 장치의 비교

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Abstract This study aimed to compare the results of delivery quality assurance (DQA) using MapCHECK and OCTAVIUS for radiation therapy. Thirty patients who passed the DQA results were retrospectively included in this study. The point dose difference (DD) and gamma passing rate (GPR) were analyzed to evaluate the agreement between the measured and planned data for all cases, Plan complexity was evaluated to analyze dosimetric accuracy by quantifying the degree of modulation according to each plan. We analyzed the monitor units (MUs) and total MUs for each plan to evaluate the correlation between the MUs and plan complexity. We used a paired t-test to compare the DD and GPRs that were obtained using the two devices. The DDs and GPRs were within the tolerance range for all cases. The average GPRs difference between the two devices was statistically significant for the brain, and head and neck for gamma criteria of 3%/3 mm and 2%/2 mm. There was no significant correlation between the modulation index and total MUs for any of the cases. These DQA devices can be used interchangeably for routine patient-specific QA in radiation therapy.

Key Words: Delivery Quality Assurance, MapCHECK, OCTAVIUS, Modulation Index, Radiation Therapy

중심 단어: 선량품질보증, MapCHECK, OCTAVIUS, 변조인자, 방사선치료

Ⅰ. Introduction

Pre-treatment patient-specific delivery quality assurance (DQA) is an essential task to verify accurate dose delivery in advanced radiotherapy techniques, such as intensity-modulated radiation therapy (IMRT), volumetric modulated arc therapy (VMAT), and stereotactic body radiation therapy (SBRT) [1-3]. Therefore, various DQA devices have been used to verify the accurate dose to the patient [4-6].

The most common method of DQA verification is to verify by comparing dose distribution and point dose difference calculated with the treatment planning system (TPS) and measured with a dosimetric QA device such as an ion-chamber and two- dimensional (2D) arrays [7]. 2D array devices such as MapCHECK (Sun Nuclear Corporation, Melbourne, FL, USA), IMRT MatriXX (IBA Dosimetry, Schwarzenbruck, Germany), and the PTW seven29 array (PTW FreiburgGmbH, Germany) are used to perform DQA in IMRT [8-11]. In addition, ArcCHECK (Sun Nuclear Corporation, Melbourne, FL, USA) and Delta4 (ScandiDos, Uppsala, Sweden) devices are used to perform 3D DQA [12-14]. The dosimetry

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check (DC) software (LAP Laser, FL, USA) is used for in-vivo dosimetry in helical tomotherapy [15]. Currently, advanced DQA devices such as the integral quality monitor (IQM, iRT Systems GmbH, Germany) have been used for portal dosimetry with an electronic portal imaging device (EPID) for radiation therapy [16].

Several studies have compared and investigated DQA results using various 2D array DQA devices for IMRT cases [13,17,18]. Chong et al. [17] demonstrate how to perform 380 IMRT DQAs using MapCHECK in various clinical cases. Son et al. [18] compared the QA results of four DQA devices for IMRT. They used the film, MapCHECK, MatriXX and EPID for patient-specific QA. Many institutions still perform DQA with 2D array devices. However, there has been no published report on the comparison of DQA results including modulation index (MI) to evaluate the impact of QA in IMRT. And, based on the comparison of DQA results using two DQA devices, we suggest that two DQA devices can be used interchangeably for pre-treatment DQA in radiation therapy. The purpose of this study was to compare the DQA results of MapCHECK and Octavius (PTW FreiburgGmbH, Germany) 2D array devices for IMRT.

II. Materials and methods

1. Patient characteristics

To analyze the DQA results, thirty patients who passed DQA measurements were randomly selected for this study (Table 1). Brain (n=10), head and neck (H&N, n=10), and rectum (n=10) cases were included in the study. Table 1 shows the patient characteristics for various cases, such as the treatment site, prescription dose, and fraction dose. All selected patients were treated with a linear accelerator (Versa HD, Elekta, Stockholm, Sweden).

2. MapCHECK™ and OCTAVIUS™ Detector

Table 2 shows the comparison of specifications between MapCHECK and OCTAVIUS devices. The 2D dose-measuring device used in this work was this MapCHECK (Model 1175, Sun Nuclear, Melbourne, FL, USA). It consists of 445 *N*-type diode detectors. These are in a 22 cm × 22 cm 2D array. MapCHECK also consists of an area of 10 cm × 10 cm with a detector spacing of 7.07 mm and an outer surrounding array with a detector spacing of 14.14 mm [13]. The active area of each detector is 8 × 8 mm^2. The maximum

Table 1. Summary of treatment planning parameters for all cases

	PTV size (cm^3)	Number of beam	Prescription dose (cGy)	Number of fraction	Fraction dose (cGy)
Brain	586.06 ± 776.02	2.20	3490.00 ± 1487.58	10.40	335.58 ± 140.41
H&N	21.71 ± 11.48	2.00	5737.00 ± 810.46	27.20	210.60 ± 4.57
Rectum	479.20 ± 223.21	2.00	4750.00 ± 799.31	20.56	323.33 ± 256.73
Total	358.29 ± 533.53	2.07	4655.86 ± 1436.09	19.34	526.41 ± 649.78

Abbreviation: H&N, head and neck; Total, the results of summation for brain, H&N, rectum cases

Table 2. Comparison of specifications between MapCHECK and OCTAVIUS devices

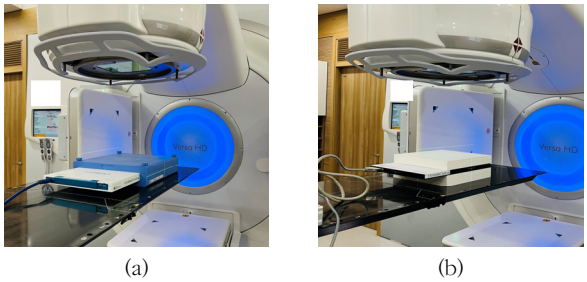
	MapCHECK	OCTAVIUS
Model No.	1175	1000 SRS
Detector type	N-type diode detectors	Liquid-filled ionization chamber
Number of detectors	445	977
Array size	22 cm × 22 cm	11 cm × 11 cm
Detector spacing	Center area: 7.07 mm Outer area: 14.14 mm	Center area: 2.50 mm Outer area: 5.00 mm
Active detector area	8 mm × 8 mm	2.5 mm × 2.5 mm × 0.5 mm (0.003 cm3)

measurement dose of this system is 330 cGy [19].

The OCTAVIUS device (1000 SRS, PTW FreiburgGmbH, Germany) is a liquid-filled ionization chamber with 977 detectors. The maximum field size is 11 cm × 11 cm and the chambers have dimensions of 2.5 mm × 2.5 mm × 0.5 mm (0.003 cm^3). The center (5.5 cm × 5.5 cm) and outer area (11 cm × 11 cm) have a spacing of 2.5 mm and 5 mm, respectively. The range of measurement dose is 0.2 to 36 Gy/min [20].

3. DQA process and analysis

All DQA plans were generated using a treatment planning station (RayStation, RaySearch Laboratories AB, Stockholm, Sweden). The source-to-detector distance was set to 100 cm and all DQA plans were delivered to two detectors as shown in Fig. 1. The planned data were transferred to SNC patient software (Version 8.4.1., Sun Nuclear, Melbourne, FL, USA) and VeriSoft (Version 7.2, PTW FreiburgGmbH, Germany). The point doses were measured at the center of the detector and in the low-dose gradient region. Then, the measurement data were compared with the results of the two devices to analyze the dose difference (DD) and gamma passing rate (GPR). The threshold for the analysis was set at 10% of the global maximum. The point dose differences were within the tolerance range of ±5 % for all measurements. The gamma passing rates with 3%/3 mm and 2%/2 mm criteria were calculated for all of the measurements [18]. We analyze the DD and GPRs results using the root-means square errors (RMSEs) for the two DQA devices for all cases. The smaller the RMSE value, the better the performance of the device.



(a) (b)

Fig. 1. Experimental setup for delivery quality assurance (DQA) using (a) MapCHECK™ and (b) OCTAVIUS™.

4. Plan Complexity

Plan complexity was evaluated to analyze the dosimetric accuracy by quantifying the degree of modulation according to each plan. For all plans, the plan complexity was analyzed using the MI, which was calculated using a previously developed algorithm [21, 22]. An increase in the MI value indicates that the beam modulation is complex. The total MUs for all plans were analyzed.

5. Statistical Analysis

A paired two-tailed t-test was performed to calculate the p-value using R statistical software (version 4.1.3). In this study, $p \leq 0.05$ was considered statistically significant.

Ⅲ. Results

1. Point dose

Fig. 2 shows the DD for the two detectors in all cases. The average DDs were within ±1.5% for all of the cases and no statistically significant differences were observed between the two devices for all clinical cases.

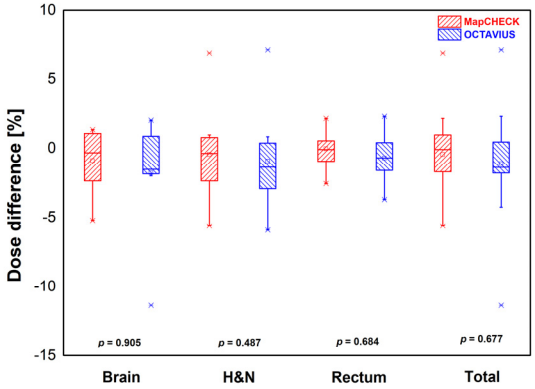


Fig. 2. Box plots of the dose differences obtained with MapCHECK and OCTAVIUS for all cases. The box plots of the MapCHECK and OCTAVIUS devices for each case are shown in red and blue, respectively.

For RMSE, the DDs were within 4.5 for the two devices in all cases (Fig. 3). The rectum case showed the maximum

RMSE (4.15) when the DQA was performed with the MapCHECK detector. The H&N case provided the minimum RMSE (0.03) with the OCTAVIUS device. The RMSE value provides information regarding the performance of the device by evaluating the comparison of the difference between the planned and measured dose.

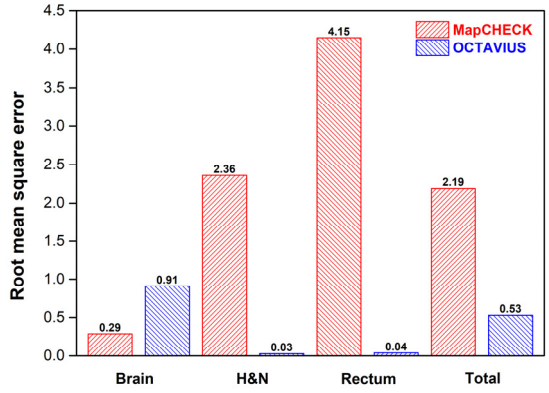


Fig. 3. The bar graphs of dose differences using the root-means square errors (RMSEs) for the two delivery quality assurance (DQA) devices for all cases. The bar graphs of the MapCHECK and OCTAVIUS devices for each case are shown in red and blue, respectively.

2. Gamma passing rate

Fig. 4 shows the results of GPRs between MapCHECK and OCTAVIUS according to the 3%3 mm and 2%/2 mm criteria for all cases. The average GPRs for MapCHECK were higher than those for OCTAVIUS for all cases. As a result, the average GPR difference between the two devices was statistically significant except for the rectum case with 3%/3 mm criteria. The difference between the two devices increased when the criterion of GPRs was 2%/2 mm.

The RMSEs with MapCHECK were within 2.3 and 4.0 for gamma criteria of 3%/3 mm and 2%/2 mm, respectively. The RMSEs with OCTAVIUS were within 2.7 and 5.9 for gamma criteria of 3%/3 mm and 2%/2 mm, respectively. For rectum case, the lowest RMSEs were obtained using MapCHECK and the RMSEs values for gamma criteria of 3%/3 mm and 2%/2 mm were 0.04 and 0.86, respectively. The highest RMSE (5.58) in OCTAVIUS was observed in the H&N case. The RMSEs of MapCHECK were lower than those of OCTAVIUS for all cases (Fig. 5).

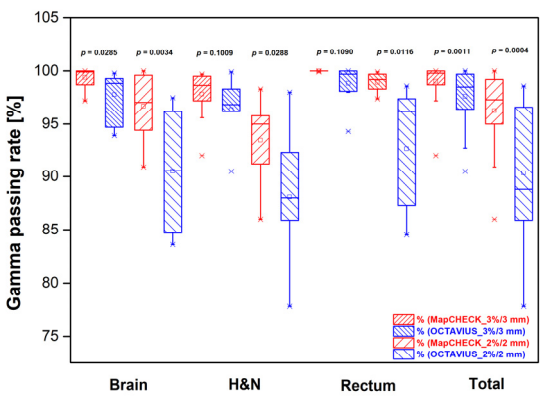


Fig. 4. Box plots of the gamma passing rate obtained with MapCHECK and OCTAVIUS for all cases. The box plots of the MapCHECK and OCTAVIUS devices for each case are shown in red and blue, respectively.

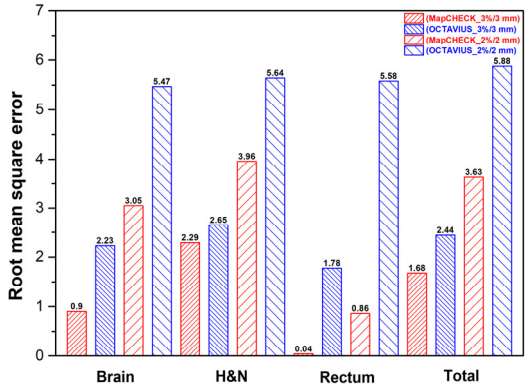


Fig. 5. The bar graphs of gamma passing rates using the root-means square errors (RMSEs) for the two delivery quality assurance (DQA) devices for all cases. The bar graphs of the MapCHECK and OCTAVIUS devices for each case are shown in red and blue, respectively.

3. Plan complexity

Table 3 summarizes the comparison of total MUs and MI between the MapCHECK and OCTAVIUS devices. The average MUs and MI were 1501.41 ± 1400.60 and 10.08 ± 2.01, respectively, and no statistically significant correlation was observed between the MI and MUs. The highest MUs and MI were 2541.14 and 10.76 in the brain case, respectively. No statistically significant correlation was observed between the MI and MUs.

Table 3. Comparison of the modulation index, and total MUs for all delivery quality assurance (DQA) plans between the MapCHECK and OCTAVIUS devices

Index	Total MU	Modulation index	Correlation coefficient (*r*)
Brain	2541.14 ± 1937.07	10.76 ± 2.22	-0.015
H&N	1002.37 ± 229.17	9.87 ± 1.97	0.018
Rectum	900.66 ± 504.68	9.94 ± 1.90	0.026
Total	1501.41 ± 1400.60	10.08 ± 2.01	-0.017

Abbreviation: H&N, head and neck; MU, Monitor Unit; Total, the results of summation for brain, H&N, rectum cases

Ⅳ. Discussion

In this study, we compared the dosimetric results between two commercially available devices (MapCHECK and OCTAVIUS) for brain, H&N and rectum cases. The DDs and GPRs were within the tolerance range for all cases. The average GPRs for MapCHECK were higher than those for OCTAVIUS for all cases. To compare plan complexity, we analyzed the total MUs and MI for each plan. However, we confirmed that there was no correlation between MUs and MI.

In all cases, the average DD between the two devices was similar as shown in Fig. 2. The RMSEs of the point dose difference for OCTAVIUS were lower than those for MapCHECK. These results show that the OCTAVIUS detector is more accurate than MapCHECK for point dose measurement, as shown in Fig. 3. However, all DD results were within criteria level of our institution. Although the DDs were within the tolerance level, there were some cases where certain ionization chambers of the two devices did not pass. However, it was confirmed that the average DD was within the acceptable range at our institution.

We confirmed that the GPRs of MapCHECK were higher than those of OCTAVIUS for gamma criteria of 3%/3 mm and 2%/2 mm for all of the cases as shown in Fig. 4. We confirmed that the MapCHECK results are consistent with those of a previously published study on linear accelerator- based IMRT. Chong et al. [17] showed that the GPRs using MapCHECK were 94.7 ± 4.0% in brain and H&N cases, respectively. They confirmed that the overall average GPRs for 3%/3 mm criteria were 93.8% for various clinical cases. Son et al. [18] showed that the average GPR was 99.04% for a gamma criterion of 3%/3 mm. They demonstrated that the MapCHECK devices showed good agreement with other 2D array detectors (Matrixx). Although, DQA was performed for helical tomotherapy (HT), the authors showed the GPRs with MapCHECK were over 96% for brain, H&N, rectum case [13]. We confirmed that the GPRs of OCTAVIUS ranged from 96% to 98% for all cases using the 3%/3 mm criteria. In addition, the GPRs of OCTAVIUS ranged from 96% to 98% 88% and 92% for all cases in case of 2%/2 mm criteria. As mentioned above, this result is relatively lower than that of MapCHECK. No other studies have compared the two detectors for IMRT DQA. Therefore, although it is difficult to directly evaluate this result with previous studies, the OCTAVIUS device has ion recombination effects for 6 megavoltage (MV) energy and higher pulse dose beam when using tighter gamma criteria. The ion recombination effects could reduce the DQA results and they showed that a correction factor should be applied during DQA [23]. Therefore, we planned to compare the DQA results when using OCTAVIUS with and without considering the ion recombination effect. Markovic et al. [24,25] showed that the GPRs using OCTAVIUS were over 90% for gamma criteria of 2%/2 mm. In this study, we did not focus on small field radiation therapy. However, we confirmed that OCTAVIUS was the tolerance range in the DQA results in several cases (Table 1 and Fig. 4). When compared with the results of previous studies, the GPRs results were similar.

We evaluated the MI using an in-house program for each plan in all cases as shown in Table 3 [21]. The most complex treatment plan showed an MI of 10.76 in the brain case, whereas the least complex treatment

plan showed an MI of 9.87 in the H&N case. These results are not consistent with those of a previous study. Du et al. [26] showed that the complex score of the H&N plans was high because of the large beam irregularity and beam modulation. In addition, they showed that there was a weak correlation between the beam complexity scores and measured dose errors. Park et al. [27] evaluated the performance of MI in VMAT. They showed a correlation between the MI values and local GPRs ($p < 0.05$). We analyzed the MI and total MUs for each plan to evaluate the correlation between the MUs and plan complexity. However, when analyzing the correlation between the two parameters, there was no statistically significant correlation, as shown in Table 3. This result may be due to the lack of DQA cases. Therefore, we are planning a study to find parameters that could predict DQA accuracy by collecting large numbers of DQA cases.

This retrospective study had several limitations. First, the data for performing all DQAs with the two devices are not the same. To overcome this problem of the timing of measurements, DQA was performed as recently as possible. The same medical physicist performed all DQA plans, measurements, and analyses. These uncertainties may have contributed to the decrease in the accuracy of the DQA measurements and statistical accuracy. Second, the number of cases in this study (30) was relatively small. Moreover, we did not analyze the treatment planning parameters that affect the DD and GPR. Finally, we did not find a correlation coefficient between the MI and MUs and the inaccuracy of DQA pattern was not analyzed with the prediction model (linear regression) in this study. To analyze and predict the treatment planning parameters affecting the DQA using machine-learning model, we are collecting a large number of DQA data. This required further investigation in a future study.

V. Conclusion

In this study, we compared dosimetric results between the two devices for pre-treatment QA. The DDs were within the tolerance range of ±5% for all of the cases. The rectum case showed the maximum RMSE (4.15) when performing using the MapCHECK detector. The H&N case provided the minimum RMSE (0.03) with the OCTAVIUS detector. The average GPRs for MapCHECK were higher than those for OCTAVIUS for all cases. The RMSEs with OCTAVIUS were within 2.7 and 5.9 for gamma criteria of 3%/3 mm and 2%/2 mm, respectively. The lowest RMSEs were obtained using MapCHECK and the RMSEs values for gamma criteria of 3%/3 mm and 2%/2 mm were 0.04 and 0.86, respectively. However, there was no significant correlation between MI and total MUs for all cases. Based on this finding, we confirmed that the two devices can be used interchangeably for routine patient-specific QA.

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