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Predicting the complexity of head-and-neck volumetric-modulated arc therapy planning using a radiation therapy planning quality assurance software

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ABSTRACT

Background/Aim: The more complex the treatment plan, the higher the possibility of errors in dose verification. Recently, a treatment planning quality assurance (QA) software (PlanIQ) with a function to objectively evaluate the quality of volumetric-modulated arc therapy (VMAT) treatment plans by scoring and calculating the ideal dose-volume histogram has been marketed. This study aimed to assess the association between the scores of ideal treatment plans identified using PlanIQ and the results of dose verification and to investigate whether the results of dose verification can be predicted based on the complexity of treatment plans.

Materials and methods: Dose verification was performed using an ionization chamber dosimeter, a radiochromic film, and a three-dimensional dose verification system, Delta4 PT. Correlations between the ideal treatment plan scores obtained by PlanIQ and the results of the absolute dose verification and dose distribution verification were obtained, and it was examined whether dose verifications could be predicted from the complexity of the treatment plans.

Results: Even when the score from the ideal treatment plan was high, the results of absolute dose verification and dose distribution verification were sometimes poor. However, even when the score from the ideal treatment plan was low, the absolute volume verification and dose distribution verification sometimes yielded good results.

Conclusions: Treatment plan complexity can be determined in advance from the ideal treatment plan score calculated by PlanIQ. However, it is difficult to predict the results of dose verification using an ideal treatment plan.

Key words: volumetric-modulated arc therapy; dose verification; PlanIQ

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Introduction

Intensity-modulated radiation therapy (IMRT) and volumetric-modulated arc therapy (VMAT) use a multi-leaf collimator (MLC) to localize the irradiation field to the target geometry and deliver a sufficient dose [1–3]. Therefore, it is a treatment method that reduces the dose for the organs at risk (OARs) compared to conventional three-dimensional conformal radiation therapy. Because of the complex intensity modulation by MLC in IMRT and VMAT, the geometric and dosimetric errors of the treatment planning system (TPS) and linear accelerator (linac) significantly impact patient outcomes. The more complex the treatment plan, the more likely that errors will occur [4]. Therefore, it is necessary to minimize the errors between them. Moreover, performing dose verification to confirm that the irradiation conditions calculated in the treatment plan can be administered to patients is necessary to maintain and improve patient outcomes. According to the guidelines, dose verification is required for all patients when IMRT or VMAT is performed [5]. Two factors may cause errors in the dose verification described above. The first is due to the quality control of the linac, and the other is due to the setting of the treatment plan. Problems in the setting of the treatment plan affect only certain patients. On the other hand, if there is a problem with the quality of the linac, it will affect all patients who receive radiotherapy at the institution. Therefore, it is essential to separate these two factors to efficiently implement medical safety during radiotherapy.

The ideal treatment plan for radiotherapy is determined by the prescription dose and the positional relationship between the target and organ at risk (OAR). The ideal treatment plan concentrates high and uniform doses on the target while maintaining a low OAR dose. If the complexity of the treatment plan can be determined in advance from the ideal treatment plan, the determination of error factors in dose verification can be simplified. In this study, we analyzed the complexity of the ideal treatment plan and the results of known dose verification and examined whether it is possible to improve the efficiency of the quality of dose verification and that of medical safety in radiotherapy. The efficiency of medical safety in radiotherapy means providing appropriate and safe radiotherapy while reducing the time required for dose verification by simplifying dose verification.

PlanIQ (Sun Nuclear, Melbourne, FL, United States) has been marketed as a quality assurance software for treatment planning. It scores the quality of treatment plans, objectively evaluates them, and calculates the ideal dose-volume histogram (DVH), which is expected to be used in clinical applications. Previous studies have evaluated the quality of treatment plans using PlanIQ [6–8] and improved the treatment plans before and after the intervention of PlanIQ [9–11]. However, no study has examined the efficiency of dose verification and dose validation using ideal treatment plans. In this study, we investigated whether the results of dose verification can be predicted by discriminating the complexity of the treatment plan from the score of the ideal treatment plan using PlanIQ. If the results of dose verification can be determined in advance from the scores of ideal treatment plans, it can improve the efficiency of quality control of linac and dose verification.

Materials and methods

Patients and clinical plans

This study included 16 patients who underwent head-and-neck VMAT with 28 treatment plans at our institution. Details of the cases are shown in Table 1. Due to the retrospective nature of this study, our website posted an information disclosure document rather than a patient explanation or consent form. The Clinical Research Ethics Review Committee of our institution approved this study. The prescribed dose for the clinical plan was 70 Gy/35 fractions at a dose encompassing 95% of the planning target volume of primary disease (PTV70). The linac used was a TrueBeam (Varian Medical Systems, Palo Alto, CA, United States) with an energy of 6 MV. Two gantry rotation angles were used for the VMAT plans: 181° to 179° in the clockwise direction and 179° to 181° in the counterclockwise direction. The collimator was set to 350° and 90°. The linac setting parameters were optimized establishing the maximum gantry speed to 6.0°/sec and the dose rate to 600 MU/min. The TPS used was Eclipse version 11.0.31 (Varian Medical Systems, Palo Alto, CA, United States), and the dose calculation algorithm was the anisotropic analytical algorithm (AAA).

Table 1. Breakdown of cases in this study

Case number	Plan name	PTV70 and PTV70N total volume [cm^3]	Right parotid	Left parotid	Spinal cord distance [mm]	Brain stem distance [mm]
Case 1	1	234.78	+	+	12.1	18.5
Case 2	1	168.56	–	–	10.9	–
Case 3	1	134.62	+	+	5.5	–
Case 4	1	447.63	–	–	12.1	–
Case 5	1	279.12	–	+	4.5	4.8
Case 1	2	225.22	+	+	13.7	18.3
Case 3	2	135.53	+	+	4.7	–
Case 5	2	270.78	–	+	5.8	5.2
Case 6	1	238.01	–	+	5.0	5.3
Case 7	1	287.77	–	+	6.3	5.9
Case 8	1	92.39	+	+	5.3	–
Case 9	1	784.35	–	–	4.2	22.0
Case10	1	79.21	+	–	36.0	40.5
Case11	1	443.55	–	–	7.6	–
Case 8	2	92.39	+	+	4.3	–
Case 7	2	264.26	–	+	7.5	4.4
Case 1	2	443.55	–	–	5.4	–
Case 9	2	658.1	–	–	4.6	25.7
Case 7	3	267.18	–	+	7.1	2.7
Case 8	2	641.3	–	–	5.1	23.0
Case12	1	217.77	–	+	6.7	23.7
Case13	1	113.56	+	–	6.4	6.8
Case14	1	100.31	+	+	13.6	–
Case12	2	150.06	–	+	7.2	26.1
Case13	2	101.41	+	–	7.0	5.2
Case14	2	106.1	+	+	14.0	–
Case15	1	959.81	–	+	5.7	–
Case16	1	228.26	–	+	6.2	57.0

A "+" sign in the parotid gland indicates a case in which dose reduction was possible. A "–" in the parotid gland indicates a case in which dose reduction was not possible. Brain stem distance is indicated for cases in which the brain stem was not present in the same axial section as planning target volume of primary disease (PTV70) or PTV of lymph node metastatic lesion (PTV70N)

Evaluation using PlanIQ

To predict the complexity of clinical plans in advance, PlanIQ was used to evaluate the quality of the treatment plans. To evaluate the quality of clinical plans using PlanIQ, we adopted the "plan quality metric" (PQM) algorithm implemented in PlanIQ [8]. The PQMs used in this study were based on 28 treatment plans for 16 patients who underwent head-and-neck VMAT at our institution, as described above. The mean values ± two standard deviations were obtained from the dose-volume relationships of the PTV, parotid gland, spinal cord, and brainstem at the dose-constrained points of the treatment plans. The PQMs are presented in Table 2.

As an index for calculating the complexity of the treatment plan from the ideal treatment plan, the feasibility DVH function, another function of PlanIQ, was used. The feasibility DVH function calculates the ideal dose distribution by defining the computed tomography (CT) image, the target and OAR contour information, and the prescribed dose to the target. An "adjusted plan quality metric" (APQM) can be calculated from these results as the ideal treatment plan score. In this study, we investigated the correlation between PQM and APQM.

Table 2. Plan quality metric (PQM) scoring table

Structure	Metric	Minimum		Maximum	
		Criteria	Score	Criteria	Score
PTV70	D98% [Gy]	67.89 [Gy]	0	69.26 [Gy]	20
	D2% [Gy]	77.76 [Gy]	0	74.76 [Gy]	20
PTV70N	D98% [Gy]	63.40 [Gy]	0	69.97 [Gy]	20
	D2% [Gy]	77.42 [Gy]	0	74.53 [Gy]	20
PTV63	D98% [Gy]	52.11 [Gy]	0	64.47 [Gy]	20
	D2% [Gy]	70.71 [Gy]	0	67.51 [Gy]	20
PTV56	D98% [Gy]	47.46 [Gy]	0	57.18 [Gy]	20
	D2% [Gy]	63.40 [Gy]	0	60.52 [Gy]	20
Parotid (affected side)	Mean dose [Gy]	50.86 [Gy]	0	20.58 [Gy]	20
Parotid (healthy side)	Mean dose [Gy]	26.83 [Gy]	0	24.09 [Gy]	20
Spinal cord	Max dose [Gy]	45 Gy <	–200	–	0
Brainstem	Max dose [Gy]	54 Gy <	–200	–	0

PTV — planning target volume

Dose verification

Dose verification was performed at three arbitrary points using a TN31014 (PTW, Freiburg, Germany) ionization chamber dosimeter. Three arbitrary measurement points were selected by the TPS in the high-dose region and the region where the dose distribution was not too steep. Details of the selection of measurement points are described below. The measurement points were selected in three sections: axial, coronal, and sagittal, using the TPS profile tool, following the method by Sasaki et al. [12]. The dose at the selected measurement points was < ±1% within ±1 cm in the anteroposterior, lateral, and vertical directions from the selected measurement points. Therefore, the measurement points were not performed at specific points, such as the iso-center, and they differed for each plan. Since the ionization chamber dosimeter used for absolute dose verification in this study has a short diameter of 2.0 mm, a long diameter of 5.0 mm, a volume of 0.015 cm^2, and a grid size for dose calculation in the TPS of $2.5 \times 2.5 \times 2.5$ mm^3, the calculated values were read as point doses. The absolute dose verification was evaluated by the difference between the dose calculated by the TPS and the dose measured. The reference is the actual dose measured by the ionization chamber dosimeter.

The dose distribution verification was performed by placing two sections of the radiochromic film, the sagittal and coronal, in the iso-center section. The radiochromic film used was EBT3 (Ashland Advanced Materials, Bridgewater, NJ, Unites States). The phantom used for absolute dose verification and dose distribution verification was the RT-2300-Cylinder (R-Tech, Tokyo, Japan). Acrylic (thickness: 5 mm) is used as the outer material of the RT-2300-Cylinder. The inside of the phantom can be filled with water. Therefore, in this study, depth scaling and phantom scaling are considered to have little influence on dose verification. Calibration data were obtained on the same day as the dose distribution verification. The calibration data were acquired by irradiating the water-equivalent phantom, Solid Water (Gammex RMI, Middleton, WI, United States) from 0 to 250 cGy at a depth of 10 cm with a field size of 10×10 cm. The irradiated radiochromic films were digitalized using a flatbed scanner ES-11000G (EPSON, Nagano, Japan) after 24 h. The scanning resolution was 75 dpi. The γ-analysis evaluated the dose distribution verification at 3 mm/3%. Dose verification using a film has more significant variability in reproducibility and coefficient of variation than dose verification using a two-dimensional detector system or a multidimensional detector system [13]. Therefore, we used a different γ-analysis from that used in Delta4 PT (ScandiDos, Inc., Ashland, VA, USA) for the multidimensional detector system; this will be described later.

γ-analysis was used and evaluated at 2 mm/3% of the absolute dose to verify the dose distribution using the Delta4 PT following the American Asso-

ciation of Physicists in Medicine Task Group (TG) 218 report [4].

Correlation between APQM and dose verification

The correlation between the two was investigated based on the results of APQM in the "Evaluation using PlanIQ" function and absolute dose verification and dose distribution verification in the "Dose verification" function. A correlation between the two can be an objective indicator to evaluate the complexity of treatment planning for dose verification without implementing treatment planning. If the complexity of treatment planning for dose verification can be discriminated, it will be possible to discriminate the error factors of dose verification, thereby improving the efficiency of medical safety in radiotherapy.

Results

Relationship between PQM and APQM

The results of PQM and APQM for 28 head-and-neck VMAT treatment plans of 16 patients at our institution are shown in Figure 1. There was a strong positive correlation between the PQM and APQM ($R^2 = 0.8522$). The smaller the total volume of PTV70 and PTV of lymph node metastatic lesions (PTV70N), the higher the APQM score. The APQM score tended to be higher in cases in which dose reduction was possible for the bilateral parotid glands. The APQM score tended to be higher when the shortest distance from PTV70 and PTV70N to the spinal cord was longer, and the APQM score tended to be higher when PTV70 and PTV70N were not present in the same axial section as the brain stem. Furthermore, since the APQM is the score of the ideal treatment plan, and the PQM is the score of the treatment plan administered to the actual patient, the APQM was never lower than the PQM.

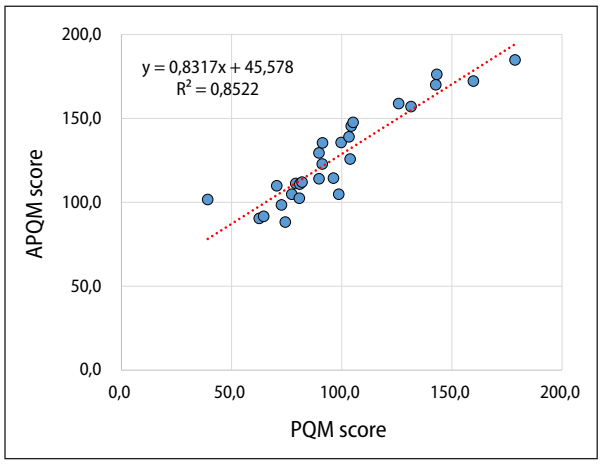

Figure 1. Relationship between plan quality metric (PQM) and adjusted plan quality metric (APQM)

Absolute dose verification using ionization chamber dosimeters and APQM

Figure 2 shows the results of the relationship between the APQM scores and the absolute dose verification by ionization chamber dosimetry. The maximum and minimum error values between the TPS and the measured values at the three measurement points per case were 4.41% and 0.03%, respectively. The mean error between the TPS and the measured values per case was –1.83% for the maximum value and 0.06% for the minimum value. In some cases, the absolute dose verification results were poor even when the APQM score was high, while in other cases, the dose verification results were good even when the APQM score was low. No correlation was found ($R^2 = 0.0494$).

Dose distribution validation and APQM

The results of dose distribution validation using the APQM score and radiochromic film or Delta4 PT are shown in Figure 3A–H. When the results of dose distribution verification using APQM and Delta4 PT (Fig. 3AB) were classified by the total volume of PTV70 and PTV70N, a slight increase in the pass rate of γ analysis was observed with increasing APQM score. In addition, the results of dose distribution verification of coronal cross sections using radiochromic film revealed a weak, negative correlation ($R^2 = 0.2142, 0.3683$) with a decrease in the pass rate of γ-analysis as the APQM score increased. The results of dose distribution verification of sagittal cross sections using radiochromic film showed no characteristic changes. The Delta4 PT is a multidimensional detector that enables verification of the overall dose distribution. However, the coronal and sagittal cross sections using radiochromic film can be verified only for the placed measurement cross section. Therefore, the results obtained may differ between the measurement placement cross section with ra-

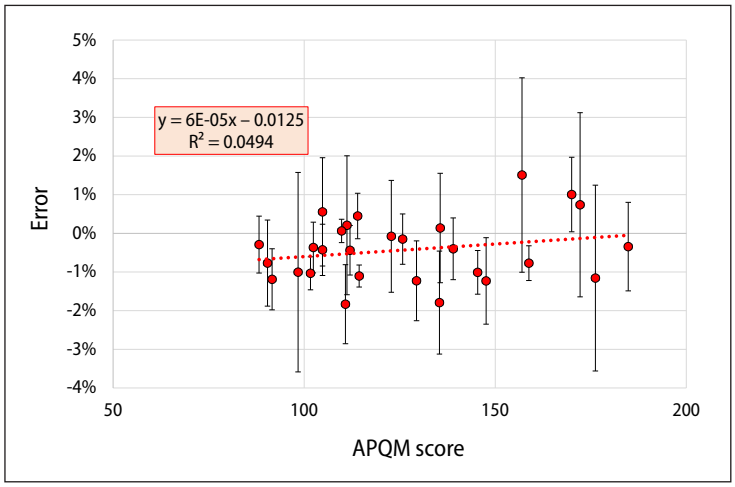

Figure 2. Results of absolute dose verification using the adjusted plan quality metric (APQM) and ionization chamber dosimeters. Red circles indicate mean values; error bars indicate one standard deviation

diochromic film and the other cross sections because the positional relationship between the target and the OAR is different.

The results of the APQM and Delta4 PT dose distribution validation for cases in which dose reduction to bilateral parotid glands was possible and those in which it was not (Fig. 3C showed a weak positive correlation ($R^2 = 0.3784$) in the pass rate of γ-analysis as the APQM score increased. However, some outliers existed in the cases shown in Figure 3D, where dose reduction was possible for the unilateral parotid gland, and the APQM and Delta4 PT dose distribution validation results showed no characteristic changes between the path rate results of the γ-analysis. The results of dose distribution validation of coronal cross sections using radiochromic film in cases where dose reduction was possible for bilateral parotid glands and those where it was not showed a weak negative correlation ($R^2 = 0.3452$) with a decreasing pass rate for γ-analysis as the APQM score increased. The coronal cross-sectional dose distribution verification results using radiochromic film for cases in which dose reduction to the unilateral parotid was possible showed an APQM score intermediate between those in which dose reduction to the bilateral parotid was possible and those in which it was not. Approximately, the pass rate of γ analysis also showed an intermediate pass rate as well as the APQM score. The results of the sagittal cross-sectional dose distribution verification using radiochromic film (Fig. 3CD) showed no characteristic changes.

When the results of the dose distribution verification by APQM and Delta4 PT (Fig. 3EF) were classified according to the shortest distance between the PTV70 or PTV70N and the spinal cord, a slight tendency for the pass rate of γ analysis to increase with increasing APQM score was observed. As the shortest distance between the PTV70 or PTV70N and the spinal cord increased, the APQM score increased. In the case of the shortest distance between PTV70 or PTV70N and the spinal cord (Fig. 3E), there were some outliers and no positive correlation ($R^2 = 0.0676$). However, a weak positive correlation was observed for the longer distance (Fig. 3F) ($R^2 = 0.2526$). There was no spinal cord in the coronal section with radiochromic film in the measurement placement section. The results shown in Figure 3E and f indicate that the higher the APQM score, the lower the coronal cross-sectional dose distribution verification pass rate using the radiochromic film. On the other hand, the pass rate of the sagittal cross-sectional dose distribution verification using the radiochromic film tended to be higher with higher APQM scores when the shortest distance to the spinal cord was short.

When the results of the dose distribution validation using APQM and Delta4 PT (Fig. 3GH) are classified according to the presence or absence of brain stems on the same axial section as PTV70 or PTV70N, the pass rate of γ analysis slightly increased as the score of APQM increased. No brain stem was observed on the measurement configuration cross section in the dose distribution verification of the coronal cross section using radiochro-

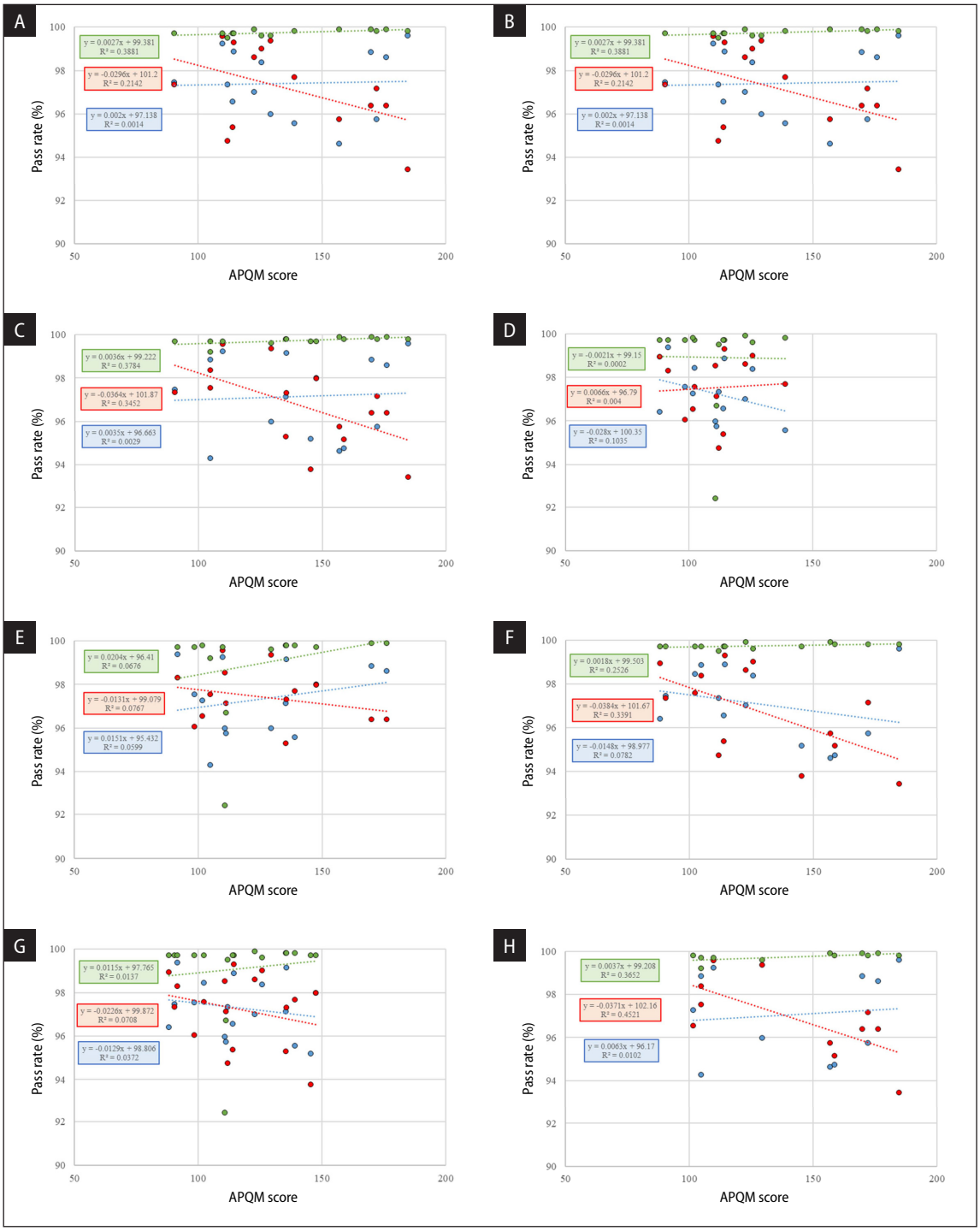

Figure 3. Results of adjusted plan quality metric (APQM) and dose distribution verification. Blue circles are sagittal planes of radiochromic films, red circles are coronal planes, and green circles are the results of Delta4 PT. **A.** Verification results of APQM and dose distribution for cases with low total volume classified by total volume of planning target volume of primary disease (PTV70) or PTV of lymph node metastatic lesion (PTV70N); **B.** Verification results of APQM and dose distribution for cases with high total volume classified by total volume of PTV70 and PTV70N; **C.** Verification results of APQM and dose distribution for cases in which dose reduction was possible or not for bilateral parotid glands; **D.** Verification results of APQM and dose distribution for cases in which dose reduction was possible for the unilateral parotid gland; **E.** Verification results of APQM and dose distribution for the shorter distance classified by the shortest distance between PTV70 or PTV70N and the spinal cord; **F.** Verification results of APQM and dose distribution for the longer cases classified by the shortest distance to PTV70 or PTV70N and spinal cord; **G.** Verification results of APQM and dose distribution for cases with brain stem in the same axial section as PTV70 or PTV70N; **H.** Verification results of APQM and dose distribution for cases without brain stem on the same axial section as PTV70 or PTV70N

mic film. Regardless of the presence or absence of brain stems on the same axial section as PTV70 or PTV70N, the higher the APQM score, the lower the pass rate tended to be. However, the pass rate of the sagittal cross-sectional dose distribution verification using radiochromic film tended to be higher with higher APQM scores in the absence of the brain stem on the same axial section as PTV70 or PTV70N.

Similar to the absolute dose verification results using the APQM and ionization chamber dosimeters, the results of the dose distribution verification are sometimes poor, even when the APQM score is high. In contrast, the results of the dose distribution verification were sometimes good, even when the APQM score was low.

Discussion

We investigated whether it is possible to predict the complexity of treatment planning in advance by determining the relationship between PQM and APQM from head-and-neck VMAT plans performed at our institution. Figure 1 shows a strong correlation between the APQM scores without treatment planning and the PQM scores calculated from actual treatment plans. Therefore, it is possible to predict the complexity of the treatment plan in advance from the patient's CT images and contour information (target location and OAR), even without implementing a treatment plan.

A specific discussion of the APQM score is given below: the APQM score is higher in cases where the positional relationship between the PTV and the OAR is farther apart because it is possible to formulate an ideal treatment plan with monotonic intensity modulation. On the other hand, the closer the positions of PTV and OAR are to each other, and the more they overlap, the more complex the intensity modulation is required. Therefore, when the complexity of the intensity modulation increases, the APQM score is lower, and the more complex the treatment plan can be predicted. In addition, because a strong correlation between PQM and APQM was observed, it is reasonable to investigate the correlation between the APQM and the dose verification results.

The results shown in Figure 2 indicate no correlation between the APQM and the absolute dose verification results. The three measurement points for absolute dose verification in this study were selected arbitrarily in the high-dose region and the region where the dose distribution is not steep. Absolute dose verification was performed in the high-dose region where PTV70 or PTV70N was present in the actual patient's body. Therefore, it is not easy to reflect the complexity of the treatment plan for each case. The measurement was performed in a region where the intensity modulation by MLC was relatively slow. Therefore, we believe that this is the reason why no correlation was observed between the APQM scores and the absolute dose verification results. In order to predict the complexity of the treatment plan from the APQM score and to observe the correlation of dose verification based on this relationship, we believe that it is appropriate to use dose distribution verification, which can evaluate the overall dose distribution.

Next, we discuss the APQM score and dose distribution validation in Figure 3. We consider that the higher the APQM score, the easier the case is for treatment planning and the more moderate intensity modulation of the treatment plan. Therefore, the higher APQM scores shown in Figures 3A and b indicate a slight increase in the pass rate of the γ-analysis of the dose distribution verification using Delta4 PT. The results of coronal cross-sectional dose distribution using radiochromic film show a weak negative correlation that decreases the pass rate of γ-analysis as the APQM score increases. The larger the total volume of PTV70 and PTV70N, the more significant the fraction of high-dose regions in the coronal section of the radiochromic film, and the smaller the fraction of low and medium-dose regions. The dose gradient on the coronal cross-sectional dose distribution using radiochromic film tended to be slow. On the other hand, from the treatment planning point of view, the larger the total volume of PTV70 and PTV70N, the more complicated the treatment planning becomes, resulting in a smaller APQM score. Therefore, the larger the total volume of PTV70 and PTV70N, the lower the APQM score and, conversely, the higher the pass rate of γ-analysis. However, even if the total volume of PTV70 and PTV70N changes, the proportion of PTV70 and PTV70N in the dose distribution on the sagittal cross section changes little. Therefore, there was no characteristic change in the pass rate of γ-analysis on the sagittal cross-sectional dose distribution.

Figure 3C shows cases where dose reduction was possible for the bilateral parotid glands. These were cases in which there were no bilateral lymph node metastases or, if there were lymph node metastases, they did not overlap with the parotid gland area. The cases in which bilateral parotid dose reduction was impossible were those in which PTV70 or PTV70N had significant overlap with the left and right parotid glands. In both cases, the intensity modulation of the treatment plan was more moderate than in cases in which unilateral parotid dose reduction is possible. On the other hand, from the viewpoint of treatment planning, the APQM score tended to be higher in cases in which dose reduction to the bilateral parotid glands was possible than in those in which it was not. Therefore, the higher the APQM score, the higher the pass rate result of the γ-analysis of the dose distribution verification by Delta4 PT. The coronal cross-sectional dose distribution verification results using radiochromic film (Fig. 3D) indicate that dose reduction of the healthy parotid gland was clinically essential for cases in which dose reduction of the unilateral parotid gland was possible. Therefore, the treatment plan was more focused on dose reduction of the healthy parotid gland compared to cases in which bilateral parotid dose reduction was or was not possible. In other words, the treatment plan did not emphasize dose reduction to the affected parotid gland. The APQM score was also considered intermediate because the treatment plans tended to be designed with intensity modulation that was intermediate between cases in which dose reduction to the bilateral parotid glands was possible and those in which it was not. The APQM score was also considered intermediate. The coronal section pass rate using radiochromic film was also considered intermediate between the results shown in Figures 3C and D.

From the results shown in Figure 3A–H, we believe that the results of the dose distribution verification for Delta4 PT measured in this study are reasonable, as the pass rate using γ-analysis was > 95% for all treatment plans, which is the acceptable value recommended by TG218 [4]. However, no correlation was found between APQM and dose verification. Therefore, it is challenging to predict dose validation from the ideal treatment plan. One possible reason for this is that the MLC leaf segmentation planned with the TPS used in this study has been accurately implemented to limit the maximum MLC leaf speed, gantry rotation speed, and dose rate so that all the treatment plans could be administered with the linac. In addition, we adopted the criteria of 3 mm/3% for the radiochromic film and 2 mm/3% for Delta4 PT in the γ-analysis. Although these criteria are used at our institution, we believe that a more stringent setting predicts the results of dose verification. Furthermore, since the number of cases in the treatment plan was small, the results changed by increasing the number of cases. However, the accurate prediction would require more data than those used in this study, and it would be challenging to perform this study at a single institution.

Previous studies have predicted the results of dose verification based on the 3-dimensional dose verification system and the VMAT treatment plan using deep learning [14], and studies have reported on the relationship between the complexity of the treatment plan (leaf gap width of MLC and irradiation field size) and dose verification [15]. In this study, we investigated whether the results of dose verification can be predicted based on CT images and contour information without treatment planning, which is a novel approach. If dose verification can be predicted based on CT images and contour information, dose verification can be improved, leading to improved medical safety in radiotherapy.

One limitation we observed in this study is that differences in machine specifications may occur when different instruments are used. Even if the same machine is used, individual differences can occur, and it is essential to confirm the correlation between PQM and APQM and between APQM and dose verification.

Conclusion

The strong correlation between APQMs and PQMs allowed PlanIQ to determine the complexity of the treatment plan a priori by the ideal treatment plan score (APQM) calculated based on the location of the target and OAR.

It is difficult to predict the results of dose verification from the APQM score in advance because no strong correlation was observed between the results of absolute dose verification using ionization chamber dosimetry, Delta4 PT, and dose distribution verification using radiochromic film and the APQM score.

Conflict of interest

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