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Original research article

Simplification of head and neck volumetric modulated arc therapy patient-specific quality assurance, using a Delta4 PT

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ABSTRACT

Background/Aim: In many facilities, intensity-modulated radiation therapy (IMRT), and volumetric modulated arc therapy (VMAT) use intensity-modulated beams, formed by a multi-leaf collimator (MLC). In IMRT and VMAT, MLC and linear accelerator errors (both geometric and dose), can significantly affect the doses administered to patients. Therefore, IMRT and VMAT treatment plans must include the use of patient-specific quality assurance (QA) before treatment to confirm dose accuracy.
Materials and methods: In this study, we compared and analyzed the results of dose verification using a multi-dimensional dose verification system Delta4 PT, an ionization chamber dosimeter, and gafchromic film, using data from 52 patients undergoing head and neck VMAT as the test material.
Result: Based on the results of the absolute dose verification for the ionization chamber dosimeter and Delta4 PT, taking an axial view, the upper limit of the 95% confidence interval was 3.13%, and the lower limit was −3.67%, indicating good agreement. These results mean that as long as absolute dose verification for the axial view does not deviate from this range, Delta4 PT can be used as an alternative to an ionization chamber dosimeter for absolute dose verification. When we then reviewed dose distribution verification, the pass rate for Delta4 PT was acceptable, and was less varied than that of gafchromic film.
Conclusion: This results in that provided the pass rate result for Delta4 PT does not fall below 96%, it can be used as a substitute for gafchromic film in dose distribution verification. These results indicate that patient-specific QA could be simplified.

1. Background

In many facilities, intensity-modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) use intensity-modulated beams formed by multi-leaf collimators (MLC). In addition to commissioning treatment planning for standard, three-dimensional conformal radiotherapy (3D-CRT), re-commissioning of the linear accelerator (LINAC) centering on the MLC, and a treatment planning system (TPS), are performed before clinical introduction. However, in TPS commissioning, it is practically impossible to confirm all irradiation conditions for every patient. In IMRT and VMAT, geometric or dose errors arising from the use of the MLC and LINAC can have a significant effect on the dose administered to patients. Therefore, guidelines state that for all IMRT and VMAT treatment plans, patient-specific quality assurance (QA) must be performed before treatment to confirm dose accuracy.[1,2]

Traditionally, patient-specific QA has been verified with respect to both absolute dose and dose distribution using an ionization chamber dosimeter and film.[2] Currently, multi-dimensional dose verification systems are widely used, due to their simplicity, and short dose verification time, and because of their merit of measuring doses more accurately with individual detectors, compared to film.[3–5] Also, a multi-dimensional dose verification system can present a dose-volume histogram (DVH) for each organ, based on the dose verification results measured by a multi-dimensional dose verification system, which is not possible using conventional film verification.[6]

2. Aim

In this study, we used a multi-dimensional dose verification system (Delta4 PT). Dose verification results achieved using this system, in comparison to those achieved using ionization chamber

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dosimeters and films (based on many cases), have not been previously reported. In addition, there have been no reports presenting a transparent approach when shifting from dose verification using an ionization chamber dosimeter and a film to dose verification using only a multi-dimensional detector system. Therefore, in this study, we used data from 52 patients with head and neck VMAT to analyze comparisons of patient-specific QA results, retrospectively, using a multi-dimensional dose verification system, an ionization chamber dosimeter, and a film. As a result, we are able to report the real possibility of simplifying patient-specific QA.

3. Materials and methods

3.1. Equipment used and experimental setup

Head and neck VMAT was performed using two gantry rotation angles (2 arcs): from 181° to 179° in the clockwise (CW) direction, and from 179° to 181° in the counterclockwise (CCW) direction. An anisotropic analytical algorithm in the Eclipse (Varian Medical Systems, Palo Alto, CA, USA) treatment planning system (TPS, version 11.0.3) was used to calculate the dose. An Optima CT 580W (General Electric Medical Systems, Waukesha, WI, USA) computed tomography (CT) system was used for imaging, using a 2.5 mm slice thickness. A TrueBeam (Varian Medical Systems, Palo Alto, CA, USA) LINAC was used, and 6 X energy was applied. The dosimeter system used was the RAMTEC SMART (Toyo Medic Co. Ltd, Tokyo, Japan) electrometer, coupled with a TN31014 (PTW, Freiburg, Germany) ionization chamber dosimeter. An RT-2300-Cylinder (R-TECH, Tokyo, Japan), which is capable of inserting an ionization chamber dosimeter and a film at any desired measurement point, served as a phantom in the conventional method. The outside of the phantom was made of acrylic, and the inside was filled with water. Gafchromic EBT3 film (Ashland Advanced Materials, Bridgewater, NJ, USA), a D.D. system film analyzer (R-TECH, Tokyo, Japan), an ES-11000 G flatbed scanner (EPSON, Nagano, Japan), and a Delta4 PT (Software version: November 2014 release), multi-dimensional dose verification system (Scandidos AB, Uppsala, Sweden) were used in our study.

This retrospective study was approved by the Institutional Review Board of our institution (Approval No. 3437).

3.2. Ionization chamber dosimeter verification gafchromic film

Absolute dose verification was performed at three points, using an ionization chamber dosimeter. The three measurement points were selected arbitrarily, and represented the high and flat-dose areas in the TPS. The measurement points were selected using the TPS profile tool in three sections: axial, coronal, and sagittal. The dose at the selected measurement point was less than ±1% within ±1 cm in the anterior–posterior direction, left–right direction, and superior–inferior direction from the selected measurement point. Therefore, the measurement points were not measured at specific locations, such as iso-centers, and varied from case to case. In this study, the short diameter of the ionization chamber dosimeter used for the absolute dose verification was 2.0 mm, the long width was 5.0 mm, the volume was 0.015 cc; the TPS dose calculation grid size was 2.5 mm × 2.5 mm × 2.5 mm. Therefore, the calculated values selected point dose. Absolute dose verification was evaluated by the difference between the dose calculated by TPS and the dose measured, while the reference was the value measured with an ionization chamber dosimeter.

Dose distribution was verified by placing two sagittal and coronal sections on the iso-center cross-section, using gafchromic film. The RT-2300-Cylinder was used as the phantom for both the absolute dose and the dose distribution verification. Calibration data were acquired on the same day as the dose distribution verification data. The data for calibration were generated by irradiating 0–250 cGy, in a 10 cm × 10 cm irradiation field, in 10 cm depth of Solid Water (Gammex RMI, Middleton, WI, USA) – which is a water-equivalent phantom. Irradiated gafchromic film was acquired after 24 h, using the flatbed scanner, with its scanning resolution set to 75 dpi. Gamma analysis (GA) was used for dose distribution verification, and the evaluation was performed at 3 mm/3%.

In dose verification using film, variations in reproducibility and the coefficient of variation are larger than dose verification using both two-dimensional (2D) and multi-dimensional detector systems.[7] Therefore, the GA used for gafchromic film, and that used for the multi-dimensional dose verification system, Delta4 PT, used different criteria.

3.3. Delta4 PT verification

Dose distribution was verified using Delta4 PT. To verify the sensitivity and placement accuracy of the Delta4 PT semiconductor detectors, irradiation was performed and measured at 10 cm × 10 cm at gantry angles of 0° and 270°. This was carried out before patient-specific QA. Also, we did not use the Delta4 PT function “Optimize Phantom Position” in this study. In dose distribution verification, the GA was used, and the dose was evaluated at 2 mm/3% of the absolute dose, in accordance with the procedure recommended by the American Association of Physicists in Medicine (AAPM) Task Group (TG) 218 report.[8] In addition, evaluations were performed using ‘axial view’ and ‘anatomy’, which are additional Delta4 PT functions, installed as three-dimensional (3D) dose estimation calculation algorithms. An axial view can evaluate the 3D dose distribution estimated inside the Delta4 PT phantom, while anatomy can evaluate estimated 3D dose distribution on patient CT images, with both algorithms based on results measured using Delta4 PT.[9]

In this study, we explored the possibility of simplifying patient-specific QA, by comparing the results of dose verification using Delta4 PT, absolute dose verification using an ionization chamber dosimeter, and dose distribution verification using gafchromic film. The results for Delta 4 PT and the other dose verifications were compared on the basis that if both results could be proved valid, only Delta 4 PT need be used for dose verification. For this reason, we evaluated the estimated 3D dose distribution based on the results measured by Delta4 PT on the CT image of the phantom used for dose verification, using an ionization chamber dosimeter and gafchromic film.

Evaluation of the absolute dose verification established using the axial view and anatomy algorithms was the same as the measurement point of the absolute dose verification using the ionization chamber dosimeter above. The evaluation target was the point dose established by the TPS, and the reference was the value obtained in each dose verification. We considered that the position error of the absolute dose verification using dosimetry measurement points and ionization chamber dosimeters in axial view and anatomy were within ±5 mm. As described in the method of verifying absolute dose using an ionization chamber dosimeter, the effect of dosimetry on measurement point setup error was approximately ±1% at the ±1 cm point. Therefore, a dosimetry measurement position error of approximately ±5 mm was considered insignificant in the context of evaluating the validity of the dose verification results, using the ionization chamber dosimeter and Delta4 PT.

3.4. Comparative analysis between dose verifications

The procedure for absolute dose verification using an ionization chamber dosimeter is illustrated in Fig. 1, while the process for absolute dose verification, using axial view and anatomy, is shown

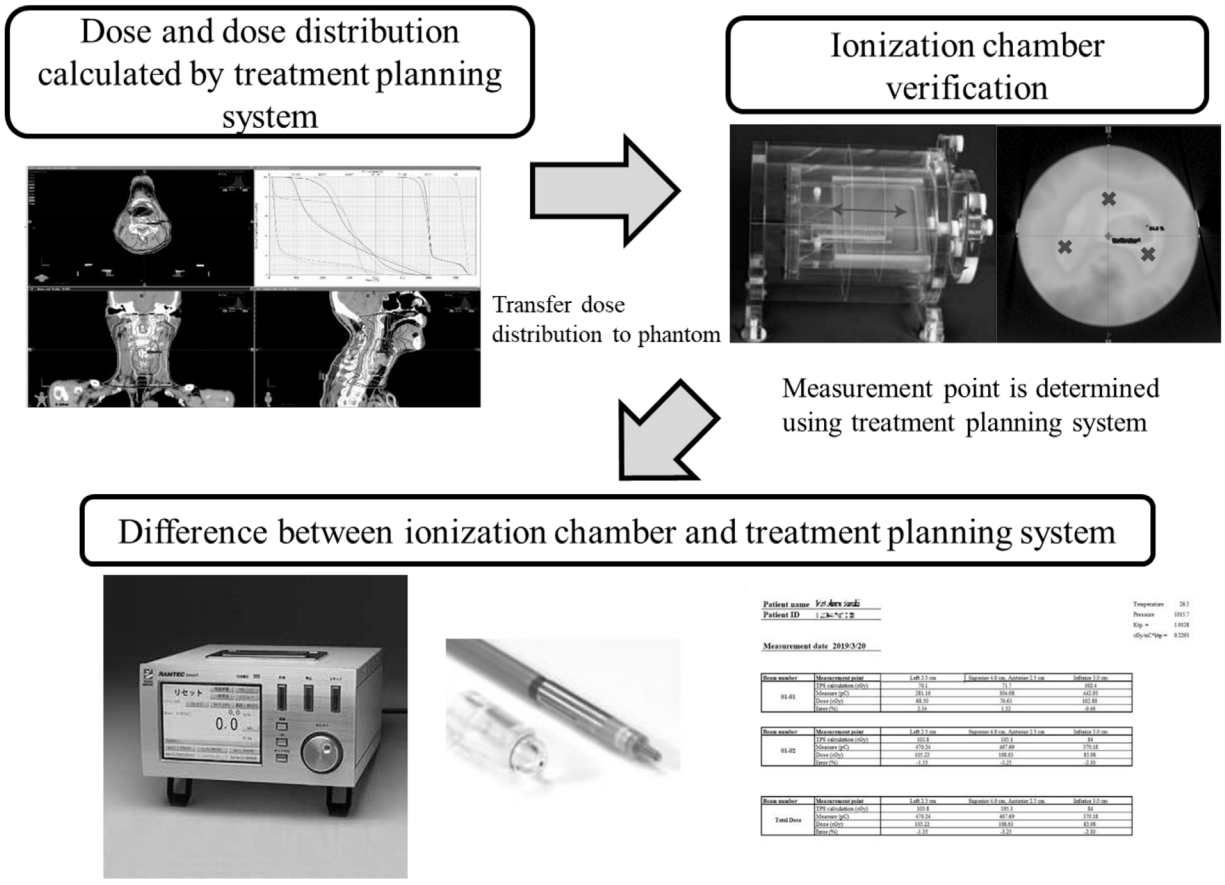


Fig. 1. Procedure for absolute dose verification, using an ionization chamber dosimeter. Crosses indicates measurement points.

in Fig. 2. Bland–Altman analysis was used to assess the degree of agreement between the three methods, in terms of absolute dose verification, and to visualize the systematic error between each pair of dose verification methods. The degree of agreement between any two dose verification methods can also be evaluated by obtaining confidence intervals for the upper and lower limits between the two methods. For dose distribution verification, we evaluated the correlation between gafchromic film and Delta4 PT pass rates.

4. Results

4.1. Absolute dose verification

Results for absolute dose verification using an ionization chamber dosimeter, and 3D dose distribution, estimated using Delta4 PT measurement results, are shown in Fig. 3. In the results for absolute dose verification using an ionization chamber dosimeter, five measurement points exceeded ±3%, while none exceeded ±5%. However, when using the axial view and anatomy, which are 3D dose distribution estimates based on the absolute dose verification measurements of Delta4 PT, there were 19 and 26 measurement points more than ±3%, respectively, and 3 and 20 points more than ±5%, respectively. This made it clear that the anatomy algorithm showed dose differences from the TPS at more measurement points than did the axial view algorithm.

The mean ± two standard deviations for the dose differences between the TPS and the ionization chamber dosimeter, axial view, and anatomy were −0.09 ± 2.50%, −0.36 ± 3.87%, and 2.36 ± 4.80%, respectively. This showed that the dose difference from TPS and the variation at each measurement point tended to increase in the following order: ionization chamber dosimeter, axial view, anatomy.

Results for Bland–Altman comparison analyses for dose verification are shown in Fig. 4. The average Bland–Altman values for the ionization chamber dosimeter and axial view, ionization chamber dosimeter and anatomy, and axial view and anatomy absolute dose verification were −0.27%, 2.45%, and 2.72%, respectively. The 95% confidence interval upper limits, based on Bland–Altman analysis results for absolute dose verification of ionization chamber dosimeter and axial view, ionization chamber dosimeter and anatomy, and axial view and anatomy, were 3.13%, 6.89%, and 6.60%, respectively. The lower limits were −3.67%, −2.00%, and −1.17%, and the confidence interval widths were 6.80%, 8.89%, and 7.77%, respectively. The degree of agreement between dose verifications was the most consistent between the dose verification by the ionization chamber dosimeter and the axial view. The least consistent level of agreement was between the ionization chamber dosimeter and anatomy dose verification.

4.2. Dose distribution verification

Results for each dose verification in the dose distribution verifications are shown in Fig. 5. The results of the dose distribution verification for GA3 mm/3%, on the sagittal cross-section using gafchromic film showed a minimum pass rate of 90.39%, a maximum of 99.67%, and an average of 97.13%. The result for verification of the dose distribution of the coronal section showed an average pass rate of 97.31%, with a minimum of 92.94% and a maximum of 99.57%. Delta4 PT's GA2 mm/3% dose distribution verification results were a minimum of 96.4%, a maximum of 100%, and an average of 99.64%. Most of the dose distribution verification results for Delta4 PT exceeded 99%, and showed a tendency for less variation compared to gafchromic film. In the gafchromic film, when com-

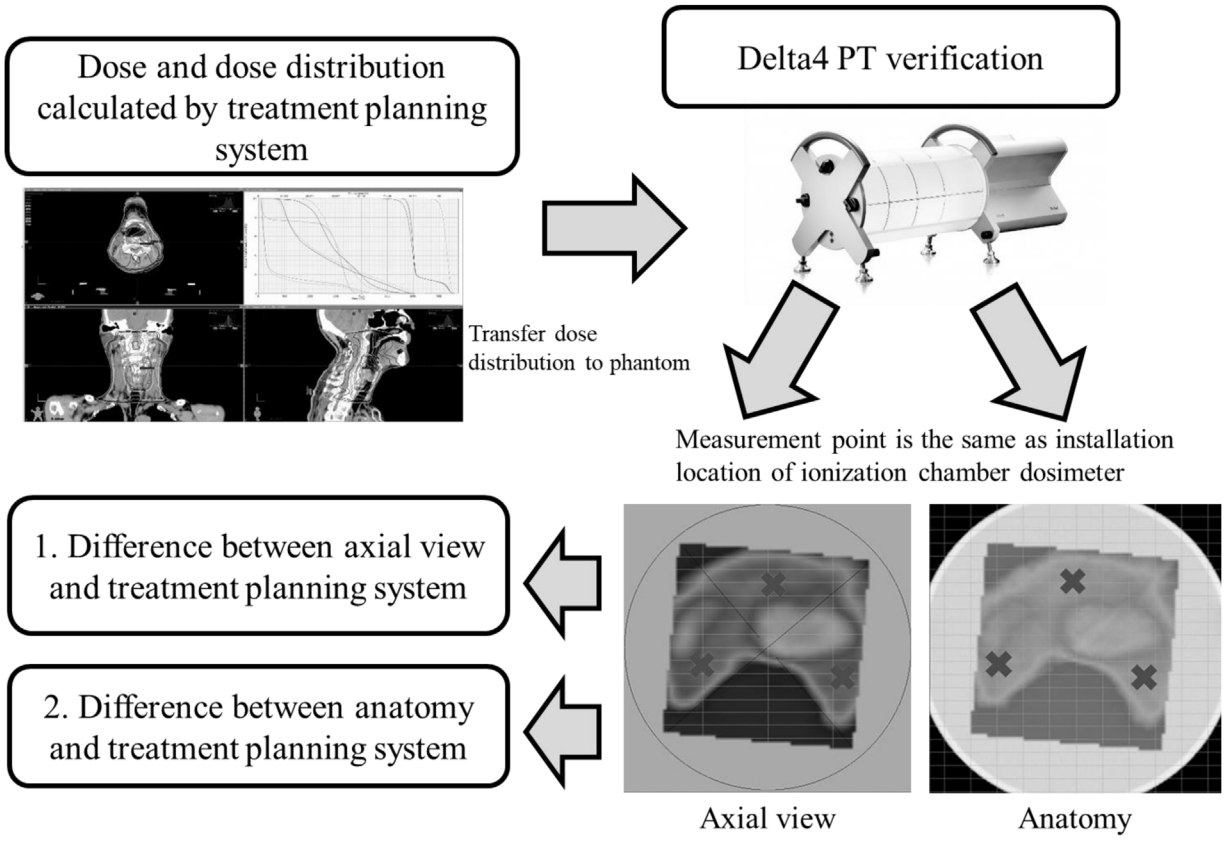


Fig. 2. Procedure for absolute dose verification, using axial view and anatomy, installed as a three-dimensional, estimated dose calculation algorithm that is an accessory function of Delta4 PT, and Delta4 PT.

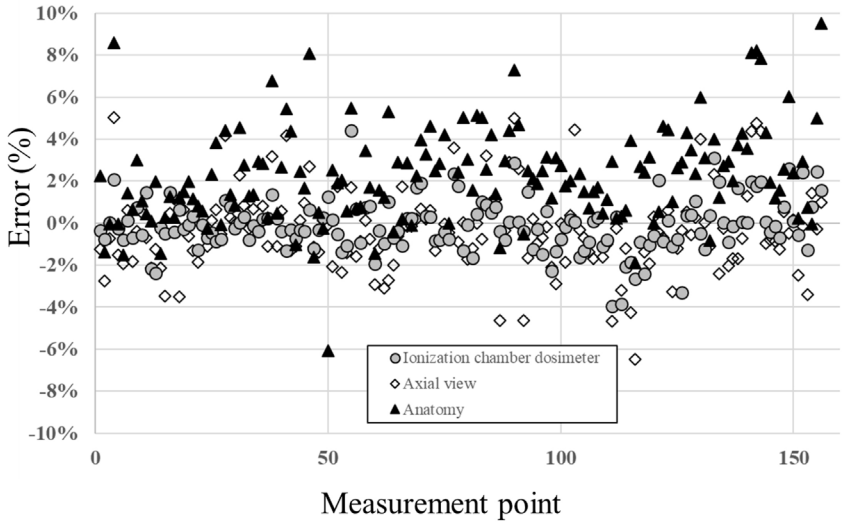


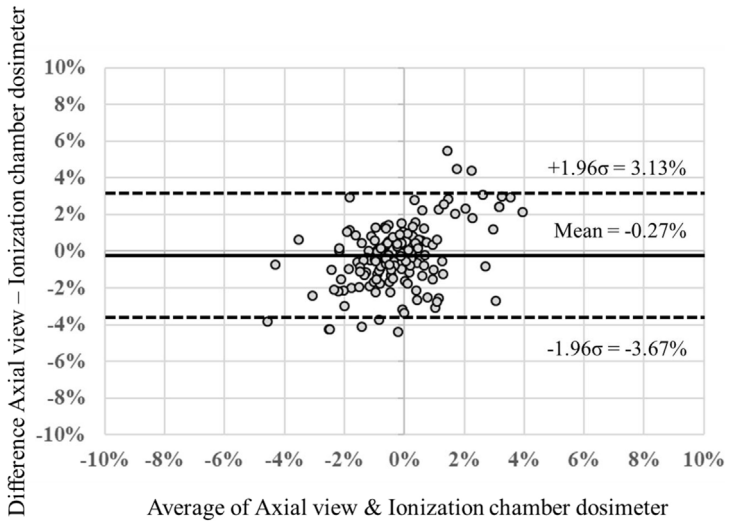
Fig. 3. Results for each dose verification, in terms of absolute dose verification.

paring the sagittal section and the coronal section, the latter tended to have less variation.

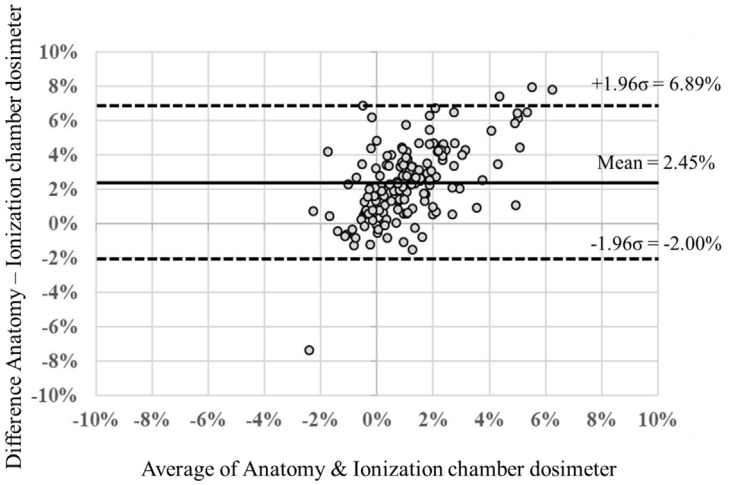
Next, the correlation for the GA pass rate between dose verification of Delta4 PT and gafchromic film, in terms of dose distribution verification, is shown in Fig. 6. From Fig. 6(a) and (b), the R2s for the dose distribution verification of gafchromic film and Delta4 PT were 0.0008 and 0.0484, with virtually no correlation. In Fig. 6(c), the R2 for the gafchromic film of the sagittal and coronal cross-sections was 0.2574, exhibiting a slightly correlated result.

5. Discussion

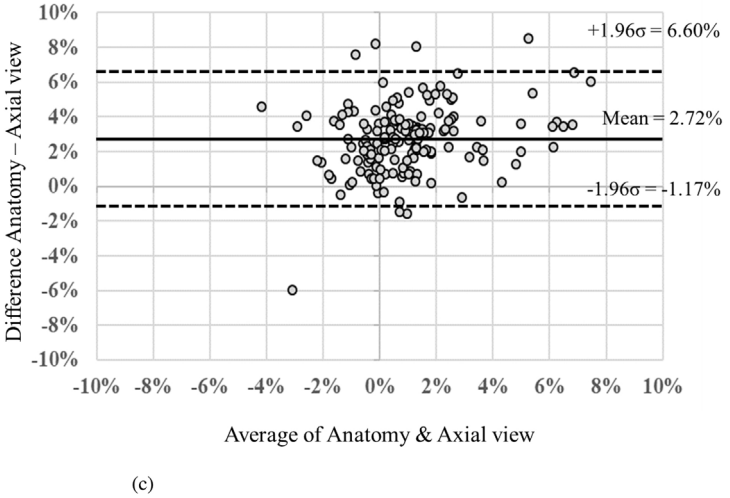
High- and flat-dose areas are considered appropriate measurement points for absolute dose verification. Therefore, we selected high- and flat-dose areas as measurement points for absolute dose verification in this study. This is why there was almost no uncertainty in the installation position error of approximately 1 cm, including for the phantom setup and the ionization chamber dosimeter alignment, in the absolute dose verification. Where the



(a)



(b)



(c)

Fig. 4. Bland–Altman analysis results during dose verification in absolute dose verification: (a) relationship between ionization chamber dosimeter and axial view; (b) relationship between ionization chamber dosimeter and anatomy; (c) relationship between axial view and anatomy. The solid line on the horizontal axis shows the average value, and the dotted lines represent the limits of the 95% confidence interval.

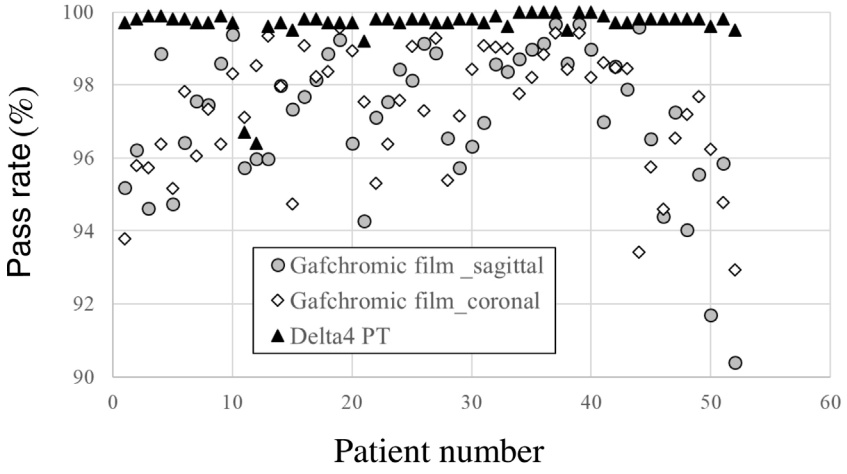


Fig. 5. Results for dose verification in dose distribution verification. Circles represent sagittal sections of gafchromic film, diamonds represent coronal sections of gafchromic film, and triangles represent Delta4 PT results.

measurement point was a low- or steep-dose area, the difference between the TPS calculation result and the delivered dose could not be accurately verified, as the result primarily reflected the uncertainty component of the installation positions of the phantom, and of the ionization chamber dosimeter.

As can be seen in Fig. 3(a), more than 95% of the measurement points were within ±3% of the dose difference from the TPS. This meant that the ionization chamber dosimeter results proved that the appropriateness of the measurement point and the validity of the dose measurements were verified in the absolute dose verification process.

In this study, we investigated the possibility of simplifying patient-specific QA. From the dose distribution obtained by the axial view and anatomy, TPS was measured at the same point as the measurement point of absolute dose verification, using an ionization chamber dosimeter. Confirming the validity between each dose verification has provided a clear approach to changing from absolute dose verification using an ionization chamber dosimeter to dose verification using only Delta4 PT.

There were some uncertainties in each dose verification, however, showing how important it was to see how well the dose verification matched standard dose verification results. In the axial view dose estimation calculation algorithm, photon beam measurement points are traced for each control point of the treatment plan, and the TPS dose calculated by the Delta4 PT phantom along each photon beam is normalized to match this measurement. The dose along the photon beam is expected to expand linearly according to the ratio of the measured dose compared to the calculated dose. In our study, the results obtained for all beams were combined, and a final estimated 3D dose distribution based on the measurement results was obtained.

The axial view is a dose estimation calculation algorithm based on simple interpolation calculations. As the dose estimation calculation algorithm of the axial view uses measurement data, the results will be similar to absolute dose verification obtained using the ionization chamber dosimeter.

On the other hand, anatomy's dose estimation calculation algorithm consists of a two-step process. Firstly, based on the dose distribution obtained by Delta4 PT, the fluence that is most likely to produce a dose distribution for Delta4 PT is estimated through optimization. Next, based on the input parameters for the resulting energy fluence per control point, the volume dose of the patient's CT dataset is calculated using the pencil beam algorithm.[10] In this study, the phantom RT-2300-Cylinder used in an ionization chamber dosimeter and gafchromic film was calculated as the volume dose in the patient's CT dataset. Energy fluence estimation is formulated as a linear programming exercise.[11] Although it is the result estimated by the calculation process of the advanced dose estimation calculation algorithm, the calculated and measured doses at the Delta4 PT detector position are due to the highly unpredictable nature of the energy fluence matrix, and to its limited resolution. Deviations have been reported to occur frequently, with IMRT and VMAT.[9]

In the axial view and anatomy, the differences in the TPS dose were larger than the absolute dose verification using an ionization chamber dosimeter. Stambaugh et al. reported that anatomy had a lower dose match with TPS, when compared to the axial view.[10] In this study, the dose difference within ±3% from TPS was at the 85.9% measurement point, in the axial view, and 71.15% in anatomy. In the axial view and anatomy, the substances to be measured are uniform substances with different CT values. However, the Bland–Altman analysis results in Fig. 4(c) show that the systemic dose tended to be higher than the axial view in a systematic manner. Both axial view and anatomy are dose distributions estimated three-dimensionally (based on the Delta4 PT measurement results), but are considered errors caused by the respective 3D dose estimation calculation algorithms. From the Bland–Altman results shown in Fig. 4(a), the 95% confidence interval was 6.80% between dose verification by the ionization chamber dosimeter and the axial view. If one of the measurement points shown in Fig. 4(a), 5%, was dismissed as an outlier, the other points agreed well. Thus, as an alternative to an ionization chamber dosimeter, we could see that it was possible to verify the axial view using Delta4 PT.

In the future, when using Delta4 PT as an alternative to validation using an ionization chamber dosimeter, multiple points in the high- and flat-dose areas of the axial view, which is a 3D dose distribution estimated from the Delta4 PT measurement results, should be selected. After that, if the dose difference from the TPS was found to be within the range of 3.13% to −3.67%, we can state that there would be no problem in verifying only with Delta4 PT. On the other hand, if the axis view results exceeded 3.13% to −3.67%, additional validation using an ionization chamber dosimeter would be required.

In this study, the gafchromic film resolution was 75 dpi (∼0.35 mm). On the other hand, Delta4 PT used in this study consists of 1069 p-type diodes, arranged in a matrix along two orthogonal planes. Each p-type diode has a cylindrical high sensitivity volume with an area of 0.78 mm^2 and a thickness of 0.05 mm, and the detectors were placed 0.5 cm apart in the central 6 cm × 6 cm area, and for 1 cm outside this area, covering the 20 cm × 20 cm area. This indi-

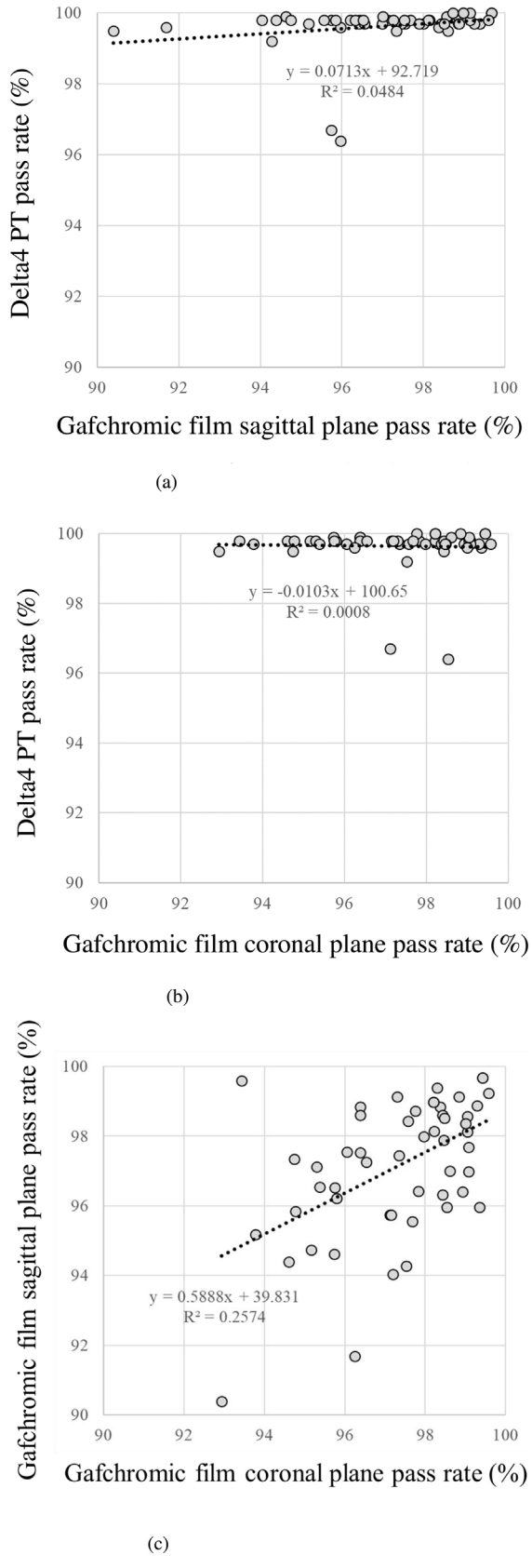


Fig. 6. Correlation for the pass rates for gamma analyses between dose verifications in dose distribution verification: (a) relationship between Delta4 PT and sagittal cross-sections of gafchromic film; (b) relationship between Delta4 PT and coronal cross-sections of gafchromic film; (c) relationship between the sagittal and coronal cross-sections of gafchromic film.

cates that Delta4 PT resolution was inferior to that of gafchromic film.

On the other hand, Delta4 PT has smaller variations in its reproducibility and coefficient of change, compared to dose distribution verification using film,[7] and has the advantage that doses can be measured more accurately by individual detectors.[3–5]

Dose distribution verification is a dose verification type that can be evaluated in a plane and by volume. Absolute dose verification using an ionization chamber dosimeter is a point-by-point measurement, so dose distribution verification using film is performed to complement these. Compared to the gafchromic film, that can be verified using only the insertion section of the film, Delta4 PT has the advantage that dose distribution verification in which volume or multiple planes can be performed, using the axial view and anatomy functions described in Section 2. Nelms et al. reported that in dose distribution verification using film, even when a good GA pass rate result was obtained, an error occurred with a partial volume dose for both the average and absolute doses, for each organ at risk. On the other hand, even if the GA pass rate was reduced, good results may occur with partial doses of the average or absolute doses for each organ at risk.[12] The GA results for this study did not use these functions and were evaluated using only certain points of the detector, making it important that the GA results for each organ were carefully observed, using the axial view.

As shown in Fig. 5, no verification below 90% resulted from GA 3 mm/3% by gafchromic film, for any dose verification. In Delta4 PT, no verifications were below 96% for all the GA2 mm/3% verification results. As shown in Fig. 6, no correlation was observed; this was considered to be due to the reproducibility, and to the coefficient of variation of the resolution, and to dose verification, due to the differences in the devices described above. If Delta4 PT were to be used in the future, as an alternative to gafchromic film, it would be safe for verifying, provided the Delta4 PT GA result was over 96%. If, however, the Delta4 PT GA pass rate turned out to be less than 96%, additional verification would be required using gafchromic film.

In this study, we examined the transition from a conventional verification system (using an ionization chamber dosimeter and film with dose verification) to a multi-dimensional detector (Delta4 PT). We consider that this approach represents a new foundation for the future simplification of patient-specific QA. After this simplification has been achieved, in addition to the validation requirements presented in this study, periodic dose validation using ionization chamber dosimeters, gafchromic films, and Delta4 PT, using the same patient data, must be performed.[13] Using data from the same patient in this periodic dose verification process will ensure that the LINAC and the measurement device are intact if the dose verification results do not deviate.

If no problem arises with dose verification using data from the same patient, and there is an error in the patient-specific QA results, then dose verification with an ionization chamber dosimeter and film is required in addition to Delta4 PT dose verification. Both dose validations must be used to determine if the errors occurred due to dose validation by the VMAT plan or by the LINAC itself.

6. Conclusions

In this study, we compared and analyzed the results of dose verification for 52 patients undergoing head and neck VMAT using a multi-dimensional dose verification system, an ionization chamber dosimeter, and a film. Based on the results of the absolute dose verification of the ionization chamber dosimeter and the axial view, the upper limit of the 95% confidence interval was 3.13%, and the lower limit was −3.67%, indicating good agreement. If absolute dose verification by the axial view does not deviate from this range, Delta4 PT can be used as an alternative to an ionization chamber dosimeter,

for absolute dose verification. It was seen from the dose distribution verification analyses that the pass rate in Delta4 PT was less varied than that achieved using gafchromic film, and that the overall pass rate itself was excellent. If the pass rate result for Delta4 PT does not fall below 96%, it can be used as a substitute for gafchromic film in dose distribution verification.

Taken together, these results suggest the possibility of simplifying patient-specific QA.

Conflict of interest

None declared.

Financial disclosure

None declared.

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