A PATIENT-SPECIFIC QA PROCEDURE FOR MOVING TARGET IRRADIATION IN SCANNED ION THERAPY

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Abstract

Three-dimensional (3D) pencil-beam scanning technique has been utilized since 2011 in NIRS-HIMAC. Beam delivery system and treatment planning software (TPS) require dosimetric patient-specific QA to check each individual plan. Any change in the scanned beams will result in a significant impact on the irradiation dose. Therefore, patient-specific QA for moving target irradiation requires additional procedure.

In an additional QA for moving target irradiation, we placed 2D ionization chamber on the PMMA plate tilted with respect to the beam axis. The PMMA plate was set on the stage of the moving phantom. The moving phantom was moved according to patient data. We measured the dose distribution for both the static target and the moving target. We compared the results for the moving target with those for the static targets by means of a gamma index analysis.

In the additional patient-specific QA, the gamma analysis between the moving and static targets showed the good agreement. We confirmed that this new technique was a beneficial QA procedure for moving target irradiation.

INTRODUCTION

Heavy-ion beams such as carbon-ion beams have attracted growing interest for cancer treatment due to their high dose localization and high biological effect at the Bragg peak. Since clinical trials using the Heavy-Ion Medical Accelerator in Chiba (HIMAC), operated by the National Institute of Radiological Sciences (NIRS), were started in1994 [1], treatments for more than 7000 patients have been successfully carried out with carbon-ion beams. To make the best use of the characteristics of a carbon-ion beam and provide flexible dose delivery, three-dimensional (3D) pencil-beam scanning is an ideal irradiation technique [2-4]. As part of the efforts to achieve ion-scanning therapy, a new treatment facility equipped with a 3D scanning irradiation system was constructed as an extension to the existing HIMAC. The 3D scanning irradiation system has been utilized for treatment since 2011.

In the scanning irradiation method, since the 3D dose distribution is achieved by superimposing doses of individually weighted pencil beams determined in the treatment planning, any change in the scanned beams will cause a significant impact on the irradiation dose. Therefore, the scanning system and its treatment planning system (TPS) require dosimetric patient-specific QA to check each individual plan and its delivery [5]. This patient-specific QA is usually performed before therapeutic irradiation, as follows. After treatment planning, the dose distribution is measured using ionization chambers set in a water phantom. In this measurement, irradiation is performed in the same manner as in the patient treatment. The measured dose profiles are then compared with the dose distribution obtained by recalculation by the TPS using a homogeneous medium instead of the patient CT data. This method allows the quality of the field to be checked.

One of the aims at the new facility is to realize treatment of a moving target by scanning irradiation. In moving target irradiation with a scanned ion beam, the interplay effect between the target motion and scanned beams is a problem, because this effect cause over or under dosage in the target volume. To overcome this problem, we developed fast scanning irradiation system with gating system for moving target [6]. However, the existing patient-specific QA is performed only in static filed. To ensure the validity of both the delivered dose and the gating system, patient-specific quality assurance (QA) for moving target irradiation requires an additional procedure. In this paper, we describe a new patient-specific QA procedure for moving target irradiation and experience with patient-specific QA.

MATERIALS AND METHODS

Patient-specific QA Procedure

The purpose of the conventional patient-specific QA is to compare the dose distribution calculated by TPS and the measured dose distribution in static field. In the additional QA for moving target irradiation, by comparing static and moving measurements, we confirm that there is no difference between them. Additionally, we check that the gating system and fast scanning system work correctly during irradiation.

Figure 1 shows the schematic workflow of patient-specific QA. In the patient-specific QA in HIMAC, the planned dose distribution is converted to the dose distribution in the water phantom, instead of the patient CT data. After that, we perform the measurement and analysis. In the measurement, a commercial 2D ionization chamber array (Octavius Detector 729 XDR, PTW Freiburg, Germany) is employed. The sensitive volume of each chamber is 5 × 5 × 3 mm, and center to center spacing is 10 mm. In total there are 729 chambers in a matrix of 27 × 27, providing a maximum field size of 27 × 27 cm. This ionization chamber array is used with an accordion-type water phantom, which was developed to

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allow measurement depth to be changed easily [5]. The remote control function of the motor makes it possible to shorten successive measurements for different depths. The measured dose distributions are compared with the planned dose by means of a 3D gamma index analysis [7]. This analysis method simultaneously evaluates the dose difference and the distance to agreement quantitatively. In the analysis, a distance to agreement of 3 mm and a dose difference of 3% are employed as accepted deviations. The criterion of QA is that more than 90% of evaluated points should meet the criterion.

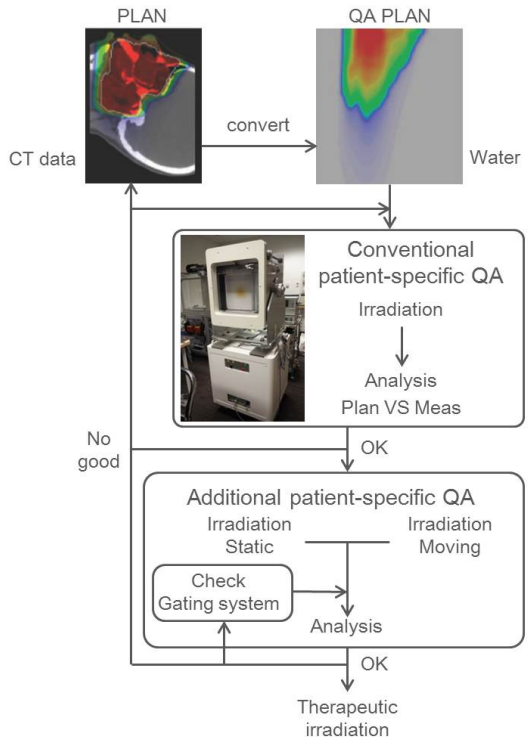

Figure 1: Schematic workflow of patient-specific QA.

In the additional QA for moving target irradiation, we place a 2D ionization chamber on the PMMA plate tilted with respect to the beam axis. Figure 2 shows the additional patient-specific QA measurement setup. The PMMA plate is set on the stage of the moving phantom (Model 008PL, CIRS). The moving phantom can be moved in the transverse direction according to the patient data. We measure the dose distribution for both the static target and the moving target. After the measurement, we derive the displacement that exhibits the smallest dose difference between the measured result for the static target and that for the moving target. The value of half the residual motion is employed as the displacement criterion. Then, considering the displacement, we compare the results for the moving target with those for the static targets by means of a 2D gamma index analysis. We used 3 mm and 3% as the accepted tolerance and the criterion of QA is more than 90% of the passed gamma in the same manner as static QA.

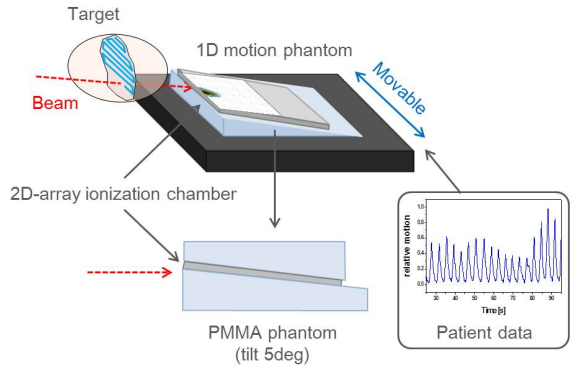

Figure 2: Schematic view of measurement setup for the additional patient-specific QA.

NIRS Scanning Irradiation System for Moving Target

All experiments were performed in the new treatment facility at NIRS-HIMAC, equipped with all the instruments indispensable for 3D scanning irradiation, including a scanning magnet, range shifter, ridge filter and beam monitors. In scanning irradiation, the dose distribution is controlled in the transverse direction by a pair of scanning magnets with beam-scanning velocities of 100 and 50 mm/ms at the isocenter. For depth scanning, the hybrid depth scanning method [8] was employed, in which 11-stepwise energy operation ranging from 140 to 430 MeV/u was used in conjunction with the range shifter. For moving target irradiation, the phase-controlled rescanning (PCR) method is implemented [6]. It can complete the several times rescanning of one slice during a single gated period of the respiration. This scheme is realized by the very fast scanning system and the intensity control system in the beam extraction from synchrotron to provide the optimum beam rate, because the period of the respiration is almost constant but the required dose is different slice by slice.

RESULTS AND DISCCUSION

Patient-specific QA in Static Field

Measurement for conventional patient-specific QA, which we called static QA, was performed after a new treatment plan was approved. The QA measurements of one field typically took 5 min, with three repeated irradiations for three different measurement depths. Figure 3 shows the typical patient-specific QA check sheet. Comparisons of 2D dose distributions, the histogram of dose difference and the histogram of the gamma index for a patient's plan are shown in the check sheet. The measured dose distributions agreed well with those calculated by the treatment planning system, and the QA criteria were satisfied in all measurements.

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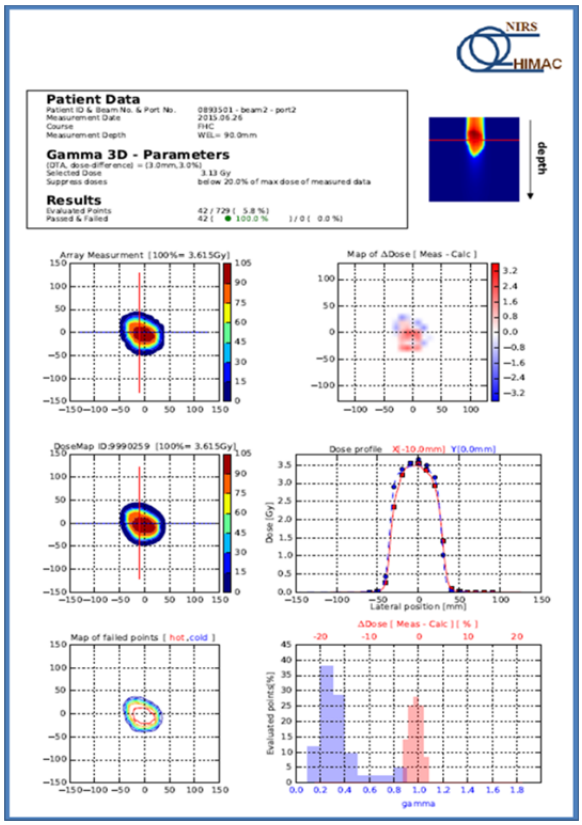

Figure 3: Typical patient-specific QA sheet. Comparison between measured dose and calculated dose by gamma index and dose difference.

Additional Patient-specific QA for Moving Target Irradiation

As a first, we checked the validity of the gating system. Figure 4 shows the time chart of the gated irradiation. The curved line shows the respiratory waveform. The residual motion was 4 mm and the gating duty was the value which was expected.

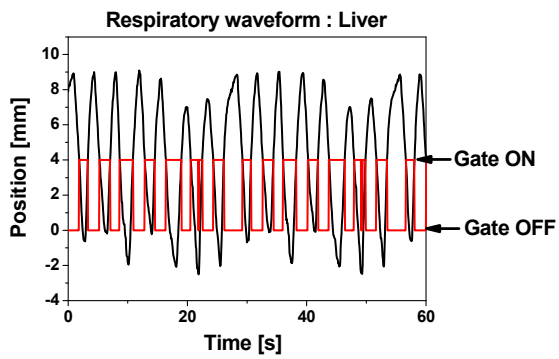

Figure 4: Typical time chart of the gated irradiation.

Figure 5 shows typical results of the additional patient-specific QA. The iso-dose lines of moving target (dashed contour) and static target (solid contour) show the dose difference. The upper and right figures show one-dimensional comparisons. The symbol and solid line show the measured dose distribution in moving field and the measured dose distribution in static field, respectively. The triangle shows the dose difference. The residual motion was 4 mm as shown in Fig. 4 and the displacement between static and moving measurements was 1.5 mm. Therefore, the displacement criterion was satisfied for this QA plan. Additionally, the gamma analysis between the moving and static targets showed good agreement. Figure 6 shows the percentage histogram of dose difference after considering the displacement between static and moving measurement. Dose variation was reasonable. We confirmed that the gating and fast scanning suppressed the interplay effect in the QA measurement.

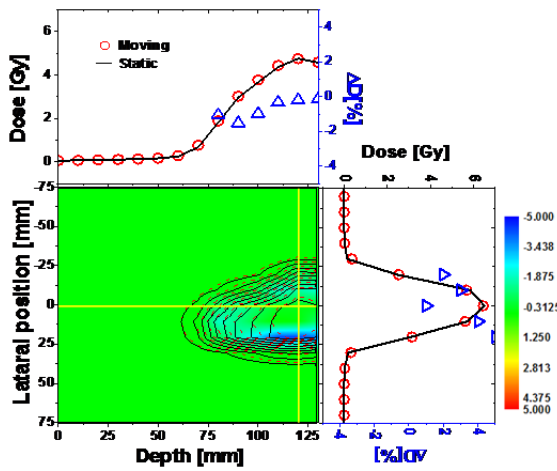

Figure 5: typical result of the additional QA. Comparison between the measured dose distribution in moving field and the measured dose distribution in static field. The upper and right figures show one-dimensional comparisons.

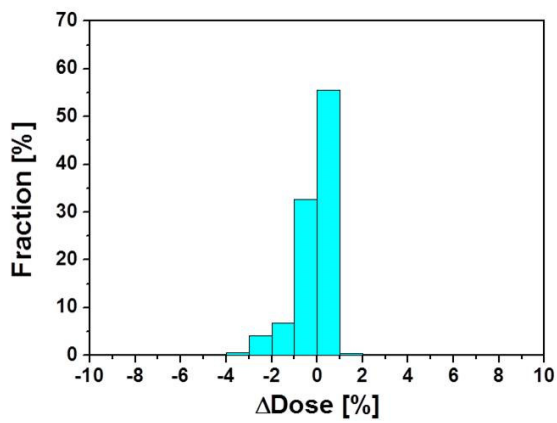

Figure 6: Percentage histogram of dose difference after considering the displacement between static and moving measurement.

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The percentages of passed gamma were compared for fourteen irradiations as shown in Fig. 7 (a). Almost all data reached more than 95% of the passed gamma regardless of the amount of residual motion. However, the passed gamma of the 8th irradiation indicated by arrows in Fig. 7 (a) was less than 95%. In PCR method, it is essential to realize the average displacement during a single gated period of the respiration. As shown in Fig. 7 (b), the probability density functions of the displacement during the gate of the 8th irradiation was not been averaging. This is due to the fact that staying time of target at max displacement was longer. However, the passed gamma was more than 90% of evaluated points and dose difference was within ±2% at almost all evaluated points.

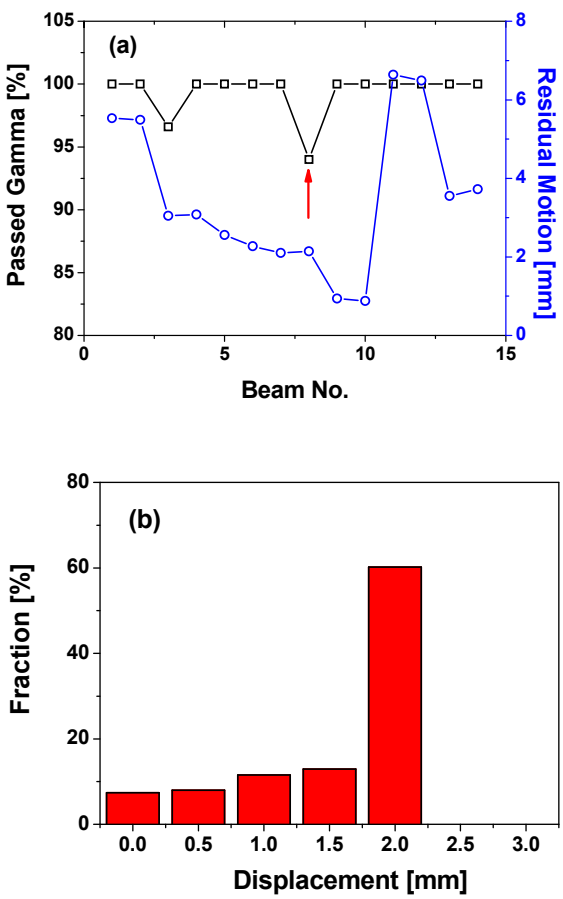

Figure 7: (a) The percentages of passed gamma and residual motion for fourteen irradiations. (b) Probability density functions of the displacement during the gate of the 8th irradiation indicated by arrows in (a).

CONCLUSIONS

We performed the additional patient-specific QA for moving target irradiation with a scanned ion beam. We confirmed that this new technique was a beneficial QA procedure for moving target irradiation. We started the treatment of a moving target by scanning irradiation to the first patient as a clinical study on March 4, 2015.

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