# A patient-specific QA procedure for moving target irradiation in scanned ion therapy

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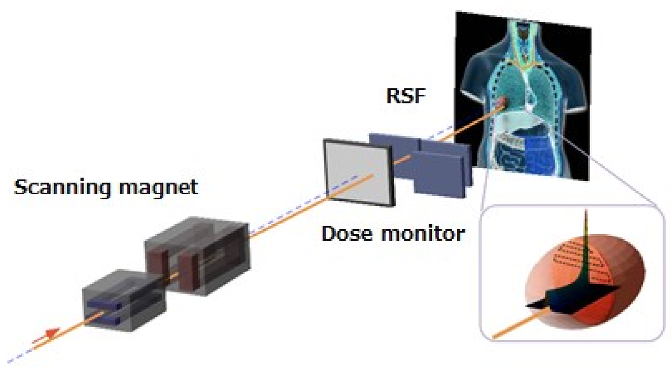
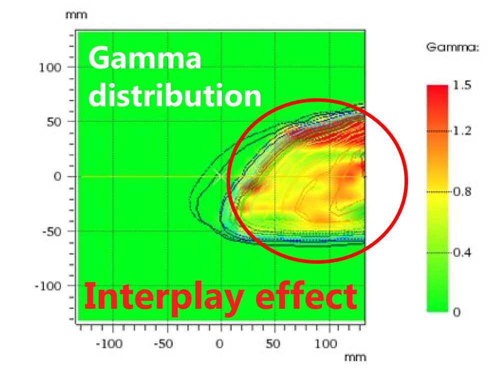
## Motivation

Three-dimensional (3D) pencil-beam scanning technique has been utilized since 2011 at the Heavy Ion Medical Accelerator in Chiba (HIMAC) [1]. Beam delivery system and treatment planning software (TPS) require dosimetric patient-specific QA to check each individual plan. Because any change in the scanned beams will result in a significant impact on the irradiation dose. Therefore, we perform the patient-specific QA for every new treatment planning before therapeutic irradiation [2].




As the existing patient-specific QA is performed only in static field, to ensure the validity of both the delivered dose and the gating system, a patient-specific QA for moving target irradiation requires an additional procedure.

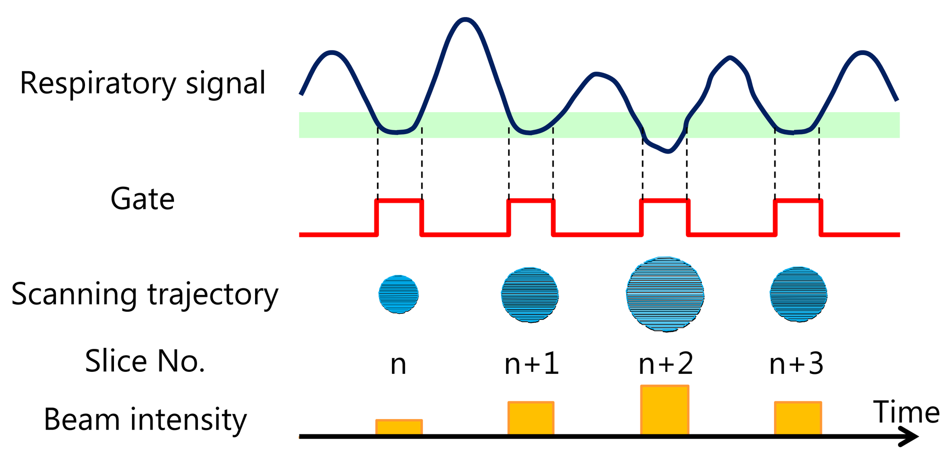
***Additional QA procedures***

→Condition of rescanning and gating system

→Dosimetric verification with respiratory motion

## Scanning system for moving target

For moving target irradiation, the phase-controlled rescanning (PCR) method is implemented [3]. 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.

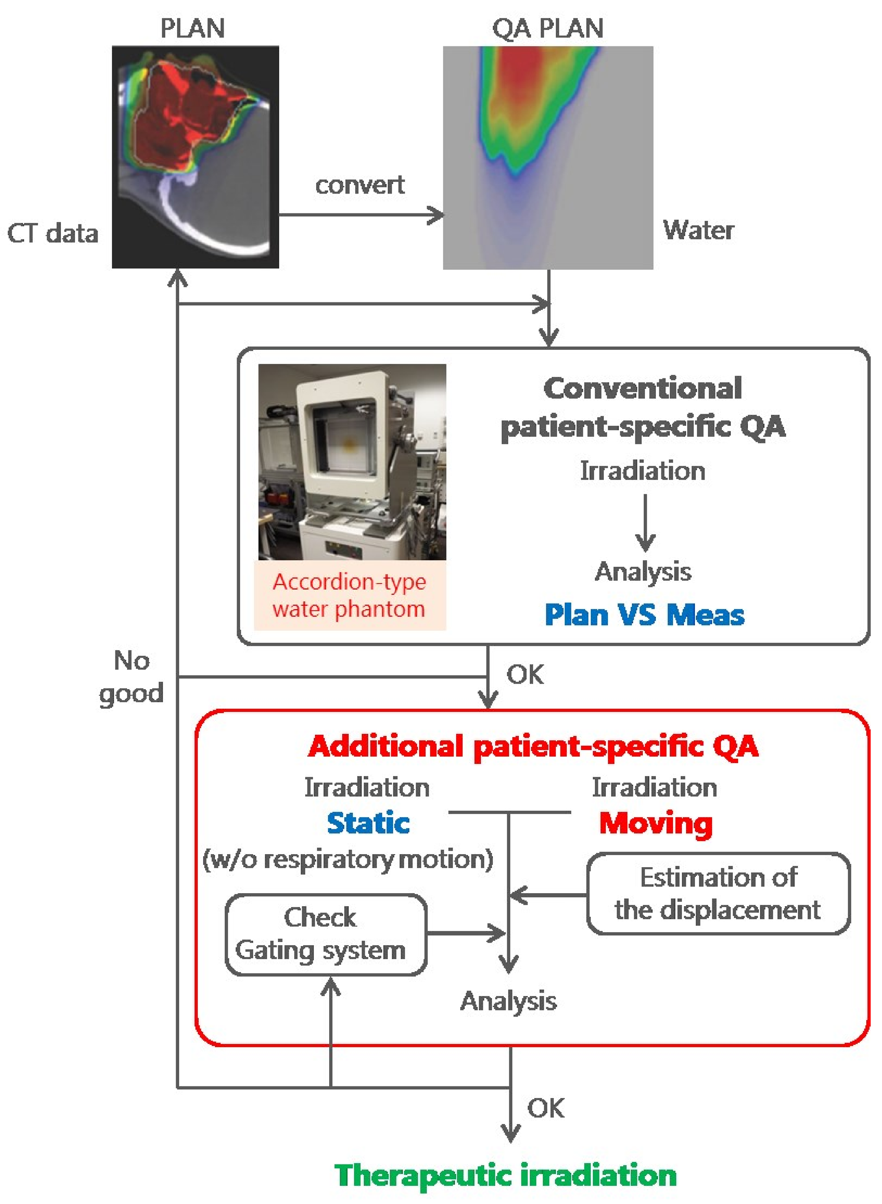



Schematic of PCR method.

## Patient-specific QA procedure

### *Patient-specific QA flow*

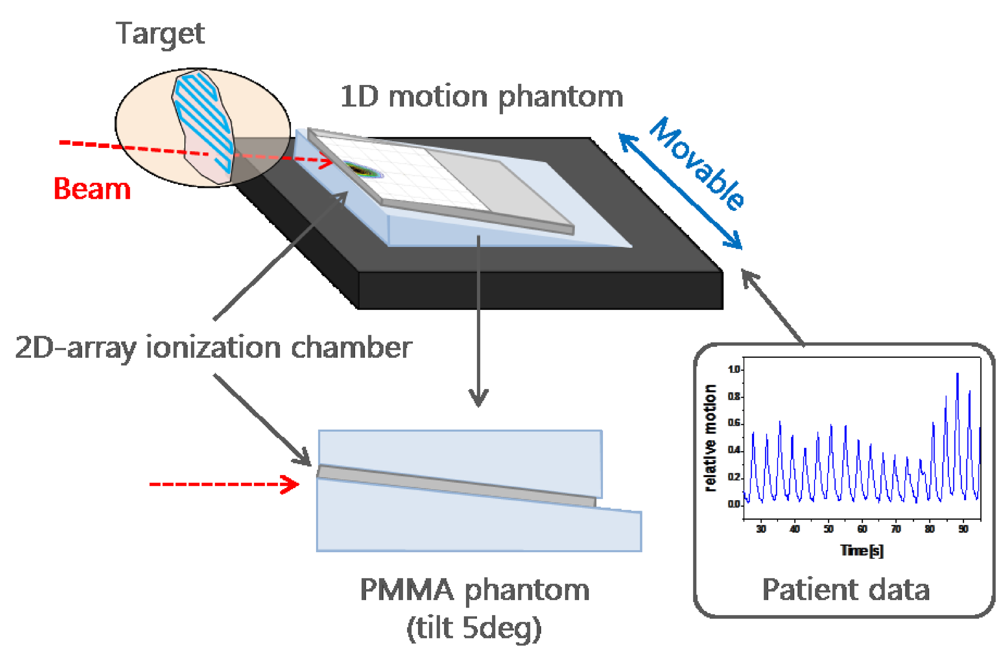
The purpose of the conventional patient-specific QA is to compare the dose distribution calculated by TPS and the measured dose distribution in static field. In the additional QA for moving target irradiation, by comparing static and moving measurements, we confirm that there is no difference between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




In the conventional QA in HIMAC [2], 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, the 2D-array ionization with the accordion-type water column is used. The measured dose distributions are compared with the planned dose by means of a 3D gamma index analysis [4].

Measurement of the additional QA is performed after the conventional QA is passed. In the additional QA, we measure the depth dose distribution for both the static target and the moving target. After the measurement, for analysis, we derive the displacement that exhibits the smallest dose difference between the measured result for the static target and that for the moving target (Auto align). Simultaneously, we estimate the log of the gating system. After that, we compare the results for the moving target with those for the static targets by means of a 2D gamma index analysis.

### *Measurement setup in an additional QA*




In the additional QA for moving target irradiation, we place a 2D ionization chamber (Octavius Detector 729 XDR, PTW Freiburg, Germany) on the PMMA plate tilted with respect to the beam axis. 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.

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. For depth scanning, the hybrid depth scanning method was employed, in which 11 beam energies ranging from 140 to 430 MeV/u were used in conjunction with the range shifter.

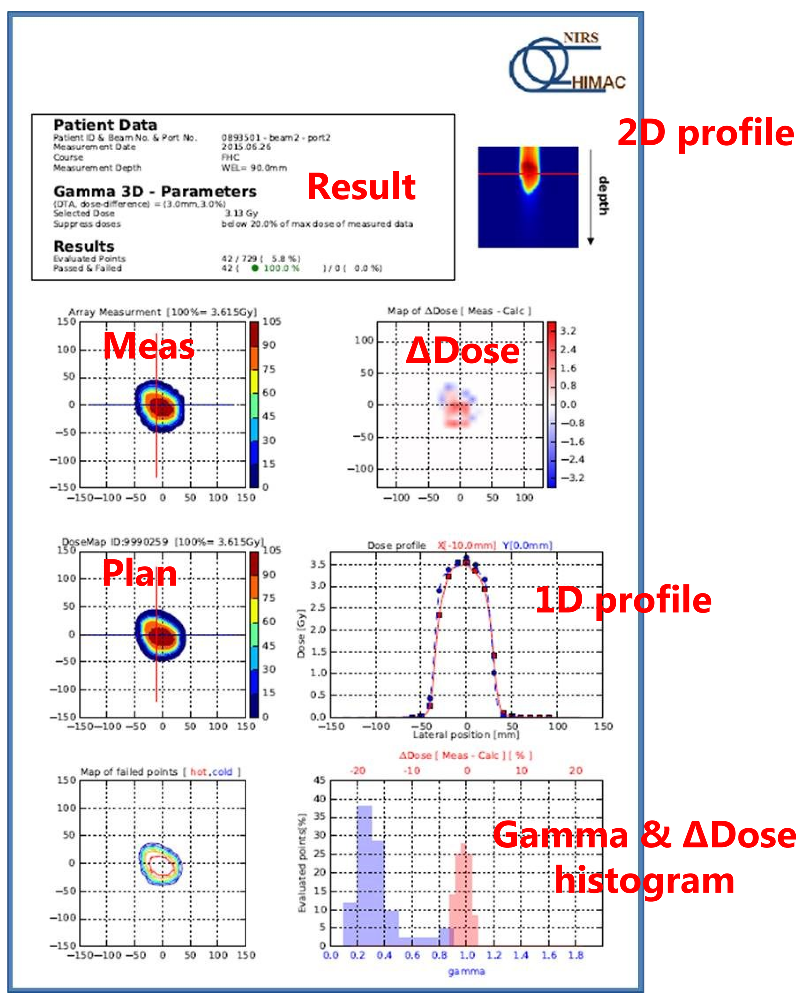
## Results & Discussions

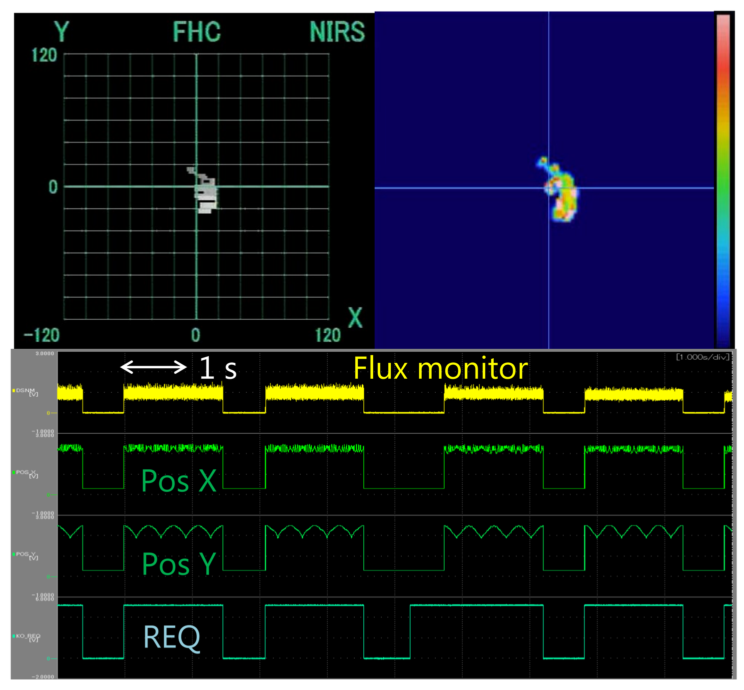
### *Patient–specific QA in static field*

In the conventional patient-specific QA, which we called static QA, the measured dose distributions agreed well with those calculated by the treatment planning system, and the QA criteria were satisfied in all measurements.

**Accepted criterion**

- **Gamma index （3 mm-3%）**
- **Check→fast scanning system**



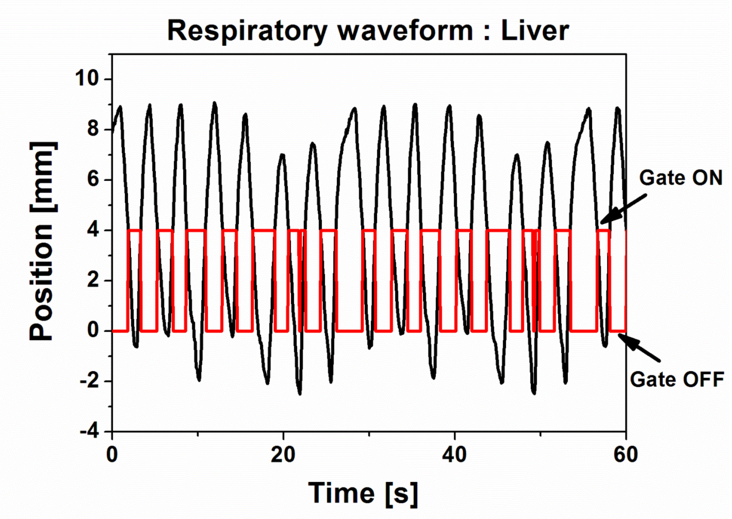




Checking Monitor system

This figure 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 TPS, and the QA criteria were satisfied in all measurements.

### *Moving QA result – Meas. vs Meas.*

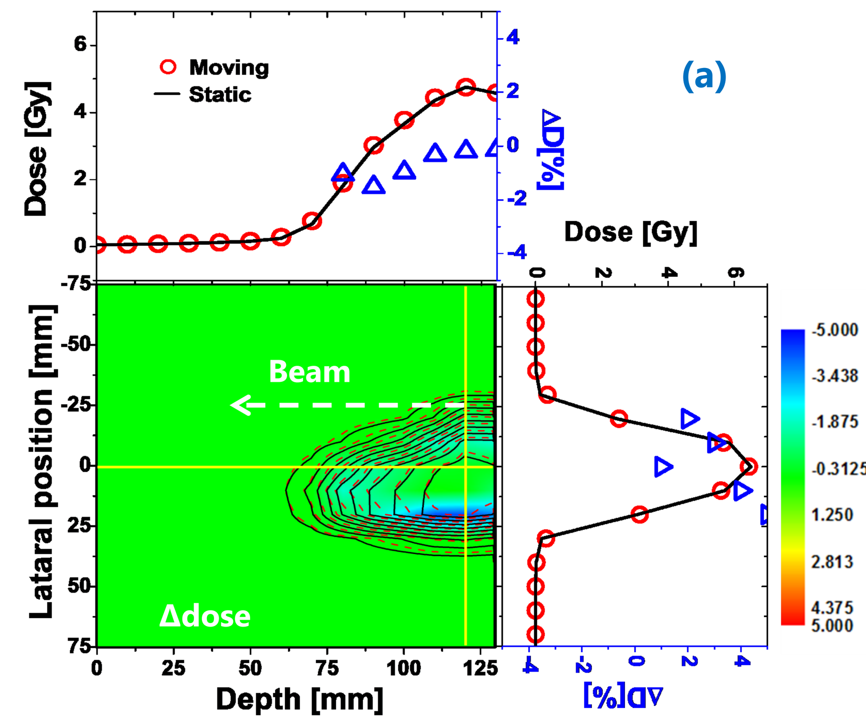
As a first, we checked the validity of the gating system. This figure shows the typical time chart of the gated irradiation. The curved line shows the respiratory waveform. The residual motion was 4 mm and the gating duty was the value which was expected.




**Accepted criterion**

- **Auto align → The half of residual motion**
- **Gamma index → 3 mm-3% (after auto align)**
- **Suppression of interplay effect in target volume**

Typical results of the Moving QA are shown : (a) Comparison between moving target and static target. 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. (b) percentage histogram of Δdose. In the consequence of auto align, the displacement between the static and the 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. We confirmed that the gating and fast scanning suppressed the interplay effect in the QA measurement.




The interplay effect in target volume is suppressed.

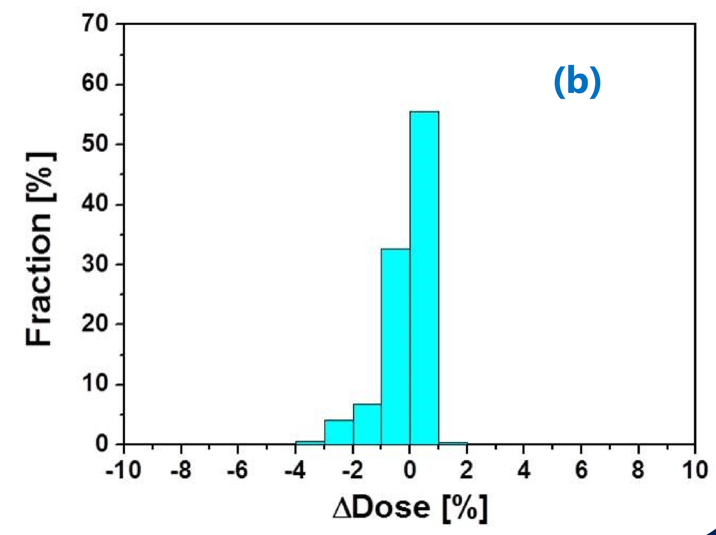
Residual motion→4 mm

Auto align→1.5 mm

Gamma pass rate→97%

***Passed !!***

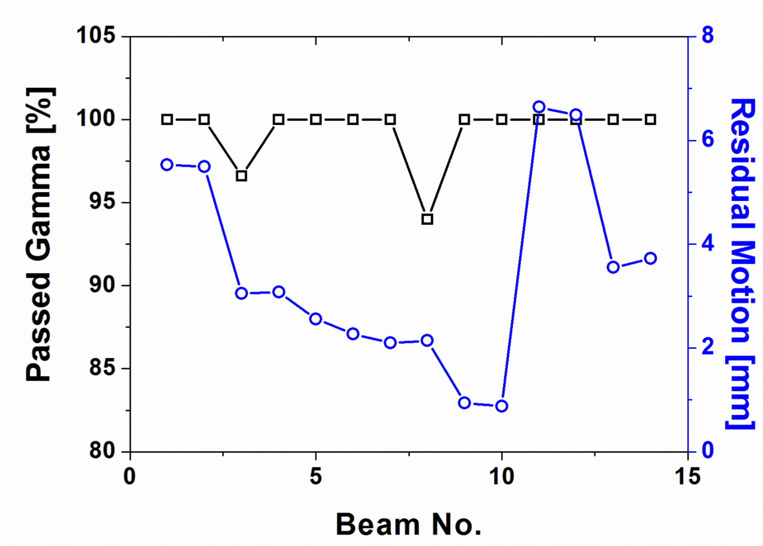
Dose variation of the moving QA is estimated from the residual motion, it is a reasonable.




## 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. The percentages of passed gamma are compared for fourteen irradiations as shown in right figure. We confirmed that almost all data reached more than 95% of the passed gamma regardless of the amount of residual motion.




**Reference**

[1] T. Furukawa et al., "Performance of the NIRS fast scanning system for heavy-ion radiotherapy," Med. Phys. **37**, 5672 (2010).
[2] T. Furukawa et al., "Patient specific QA and delivery verification of scanned ion beam at NIRS-HIMAC," Med. Phys. **40**, 121707 (2013).
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[4] D. A. Low et al., "A technique for the quantitative evaluation of dose distributions," Med. Phys. **25**, 656 (1998).

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