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Development of a four-dimensional (4D) dose distribution verification system using a plastic scintillator and semiconductors:

comparison of the light distribution and the dose distribution, both integrated along the longitudinal axis

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ABSTRACT

Purpose: Our research group developed a four-dimensional (4D) dose distribution verification system consisting of a cylindrical plastic scintillator (PS) and multiple semiconductor detector array. In this study, agreement between measured light distribution and planned dose distribution was evaluated.

Methods: The developed system consisted of the PS (15 cm diameter and 29 cm height) and multiple semiconductor detector array (ArcCHECK, SunNuclear Corp., FL, USA). A 16-bit cooled Charge-Coupled Device (CCD) camera was used to record dynamic images of the three-dimensional scintillation light distribution integrated along the longitudinal axis. In this study, dose and dose-rate dependency of the amount of light recorded by the CCD camera, and agreement between recorded light distribution and dose distribution of intensity-modulated radiotherapy (IMRT) plan calculated by RayStation version 14.0 (RaySearch Laboratories AB, Sweden) were investigated. 6 MV and 10 MV photon beams of TrueBeam linac (Varian Medical Systems, Palo Alto, CA, USA) were used. Dose difference and pass rate of gamma-analysis (3%/2 mm) were calculated for the area above the 10% isodose curve. The scintillation light diffusion in the PS was corrected by a point spread function defined by a double Gaussian.

Results: Dose dependency was linear for absorbed doses ranging from 0.7 to 9.1 Gy at the center of the PS. Dose-rate dependency was within ± 1% for absorbed dose-rate ranging from 0.7 to 4.6 Gy/min at the center of the PS. Light distribution and dose distribution of IMRT plan showed good agreement, with the mean dose difference of 0.26 ± 0.73% and the gamma-analysis pass rate of 99%.

Conclusion: These results indicate that absorbed dose can be obtained from light distribution. The developed 4D dose distribution verification system successfully obtained light distribution corresponding to absorbed dose distribution by recording scintillation light from the PS using the CCD camera.

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INTRODUCTION

As the irradiation methods with field sizes and dose rates variation during irradiation have become widespread, a four-dimensional (4D) dose distribution verification system has become essential to accurately evaluate the dynamic changes in dose distributions.

PURPOSE

To develop the 4D dose distribution verification system.

METHODS AND MATERIALS

1. Principle of 4D dose distribution verification

- The system consisted of a plastic scintillator (PS) (Fig.1 (a)) and a semiconductor detector array (ArcCHECK, SunNuclear Corp., FL, USA) (Fig.1 (b)).
- A 16-bit cooled CCD camera (Fig.1 (c)) was used to acquire time-resolved images of the three-dimensional (3D) scintillation light distribution integrated along the longitudinal axis.

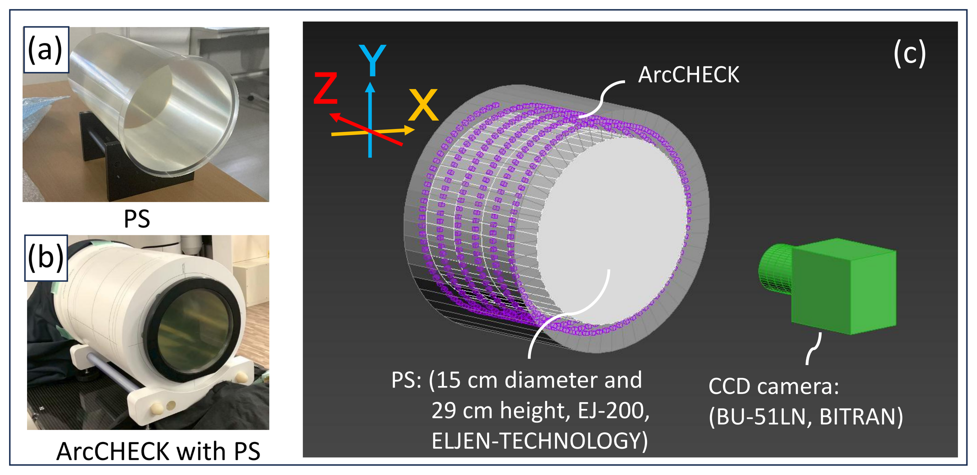

Fig.1 Schematic diagram of 4D dose distribution verification system. The scintillation lights caused by X-ray irradiation to the PS are recorded by the cooled CCD camera.

- The 3D dose distribution (Fig.2 (c)) is reconstructed from recorded light distributions (Fig.2 (a)) and ArcCHECK data decomposed in the Z-axis (Fig.2 (b)).
- The 4D dose distribution (Fig.2 (d)) is obtained as a sequence of 3D dose distributions with 123.5 msec intervals.

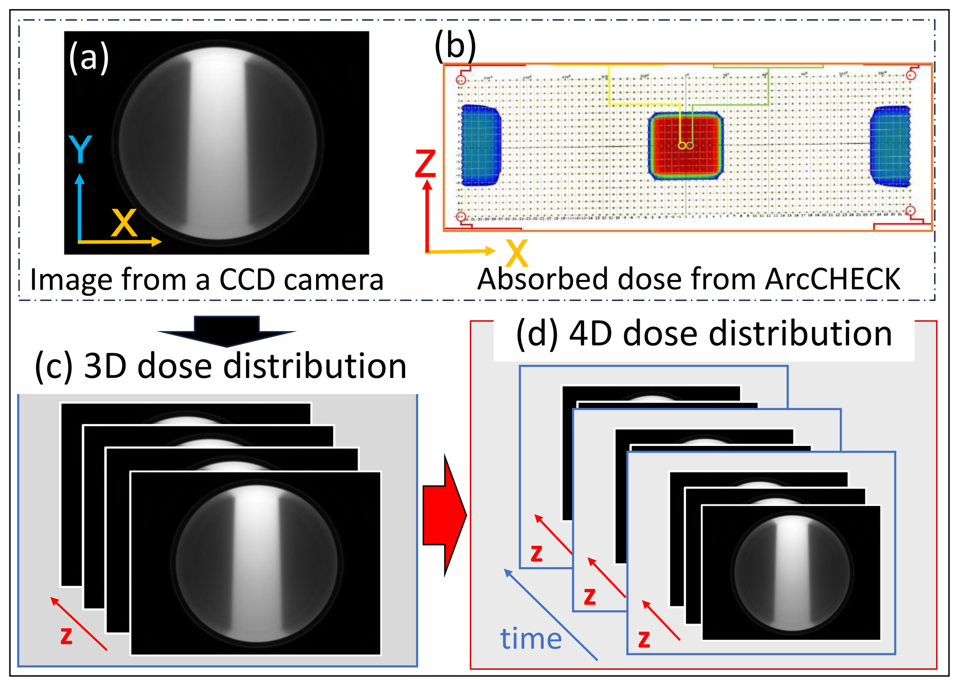

Fig.2 Reconstruction method of 4D dose distribution. The ArcCHECK data contains both Z-axis spatial information and time-resolved data acquired every 50 msec.

2. Measurement setup

- Photon beams of TrueBeam linac (Varian Medical Systems, Palo Alto, CA, USA) were used.
- During recording, measurements were performed under the darkest possible room conditions by turning off the treatment room lights.

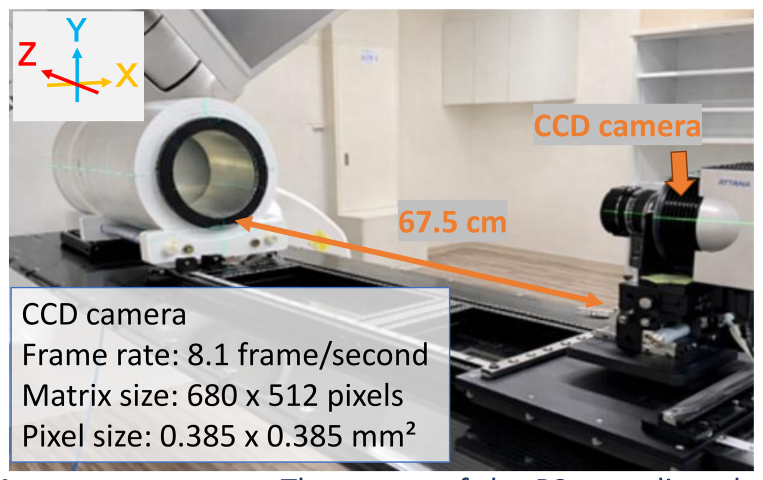

Fig.3 Measurement setup. The center of the PS was aligned with the isocenter. The CCD camera was placed 67.5 cm away from the surface of the PS.

3. Recorded images

- The images were subtracted using a background image defined as the average of 1,000 unexposed frames.
- The area to be evaluated was the region within a radius of 173 pixels (66.4 mm) from the center of the PS.

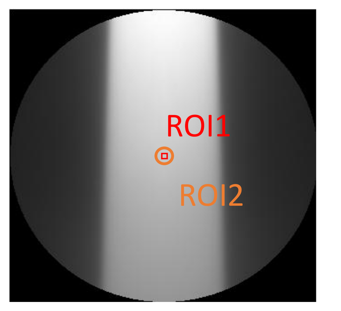

Fig.4 The recorded light distribution of a 5 x 5 cm² field recorded by the CCD camera.

4. Evaluation of the system

4.1. Characteristics of the amount of light

- The dose dependency and the dose-rate dependency of the amount of light for 6 MV and 10 MV photon beams with 5 x 5 cm² field size were examined, at the region of interest 1 (ROI1, 10 x 10 pixels, Fig.4).

4.2. Comparison between the recorded light distribution and the dose distribution from the treatment planning system (TPS)

- Two IMRT plans for the prostate case (AAPM TG-119) were evaluated: a seven-field sliding window technique and a dual arc VMAT technique.
- The TPS used in IMRT planning was RayStation version 14.0 (RaySearch Laboratories AB, Sweden) and the planned dose distribution was integrated along the longitudinal axis.
- The scintillation light diffusion in the PS was corrected by a point spread function (PSF) defined by a double Gaussian.

A. X-axis profile and Y-axis profile

The recorded light distribution and the dose distribution from the TPS in X-axis (Y = 0, the yellow line in Fig.5) and Y-axis (X = 0, the blue line in Fig.5) profiles were compared.

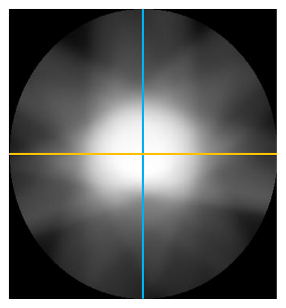

Fig.5 The recorded light distribution of IMRT plan. The center of the PS was defined as (0,0).

B. Dose difference (DD) and gamma-analysis

DD and pass-rate of gamma-analysis (3%/2 mm) were evaluated.

RESULTS AND DISCUSSIONS

1. Characteristics of the amount of light

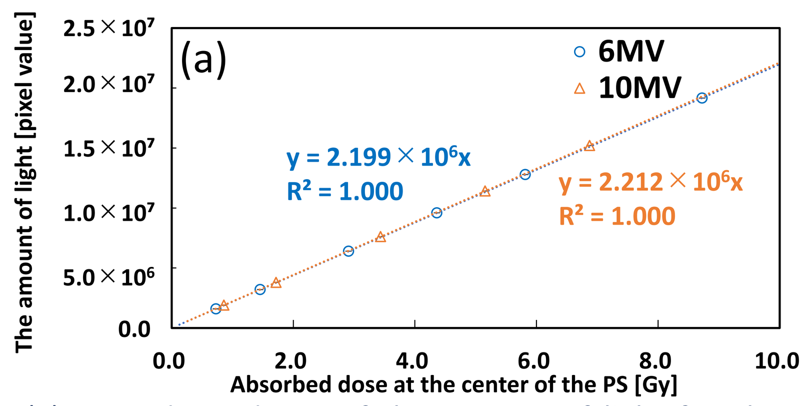

Fig.6 (a) Dose dependency of the amount of light for absorbed dose. The dose-rate was fixed at 600 MU/min (equivalent to 4.4 Gy/min for 6 MV beam and 5.2 Gy/min for 10 MV beam at the center of the PS).

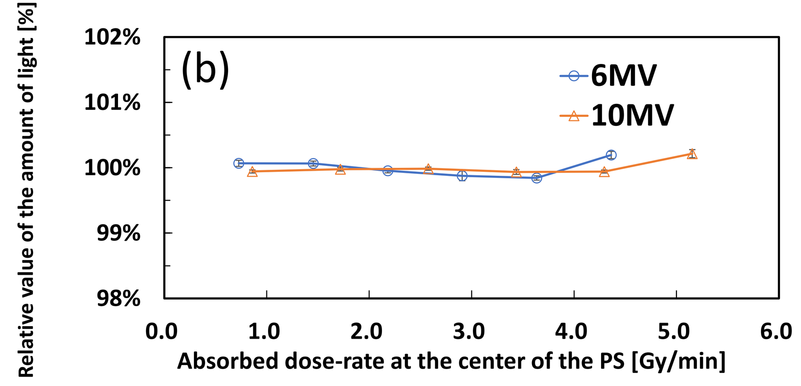

Fig.6 (b) Dose-rate dependency of the amount of light. The dose-rate varied from 100 to 600 MU/min, and the irradiated monitor unit was set to 100 MU (equivalent to 0.73 Gy for 6 MV beam and 0.86 Gy for 10 MV beam at the center of the PS).

- The dose dependency on the light amount showed linearity (Fig.6 (a)).
- The results of dose-rate dependency were within ± 0.5% (Fig.6 (b)).

2. Comparison of the recorded light distribution and the dose distribution

A. X-axis profile and Y-axis profile

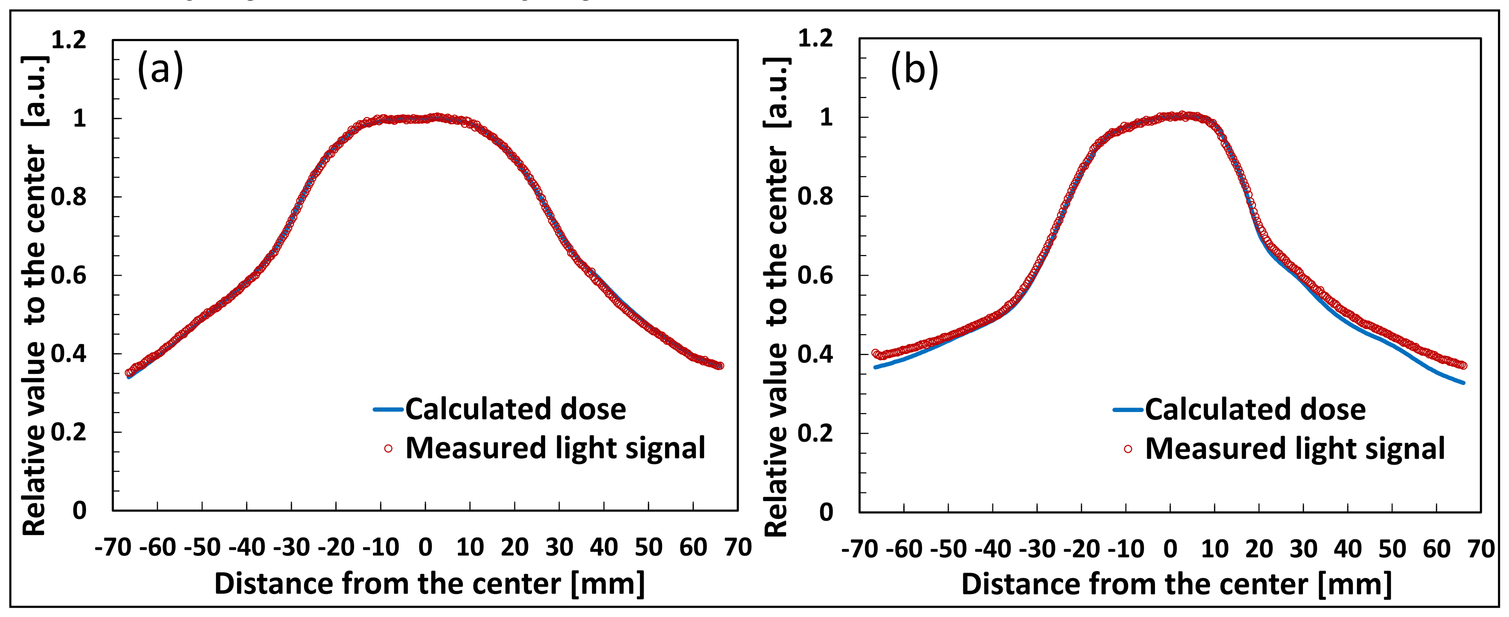

Fig.7 Comparison of the sliding window plan: X-axis profile (a) and Y-axis profile (b).

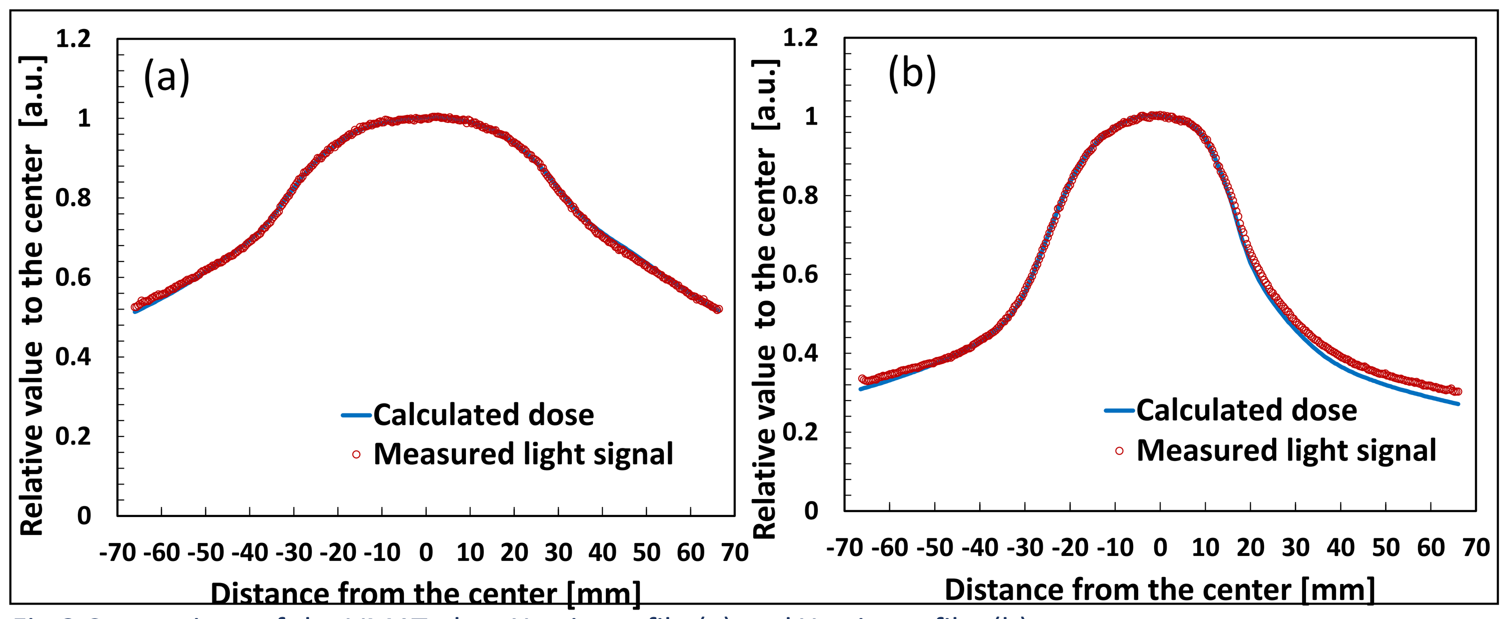

Fig.8 Comparison of the VMAT plan: X-axis profile (a) and Y-axis profile (b).

- The shape of the recorded light distribution and the dose distribution from the TPS show good agreement in both plans. The difference observed in the low-dose region was less than 4.7% in the sliding window plan (Fig.7 (b)) and less than 3.5% in the VMAT plan (Fig.8 (b)).

B. DD and gamma-analysis

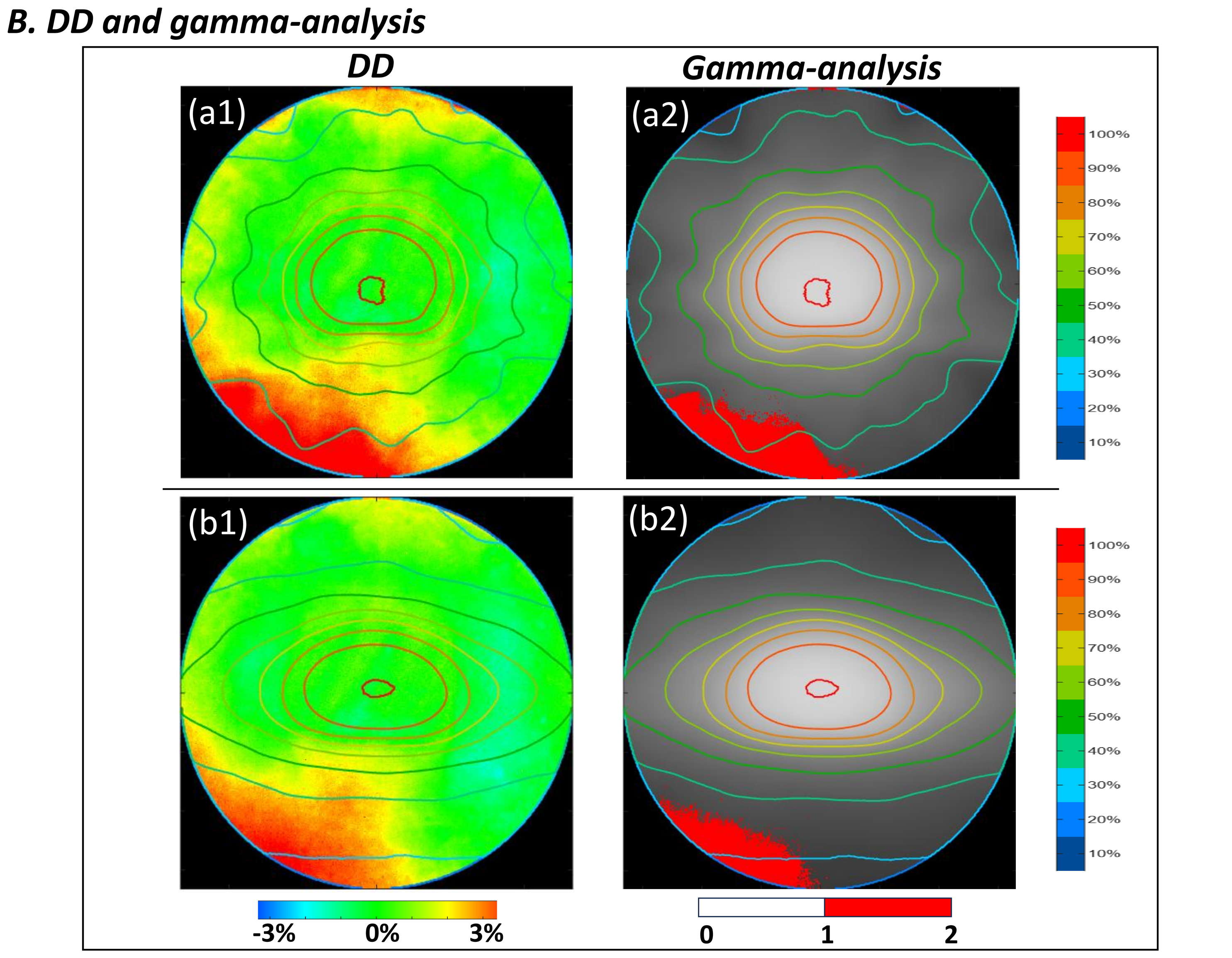

Fig.9 Comparison of the recorded light distribution and the dose distribution from the TPS. (a1) and (a2) show the sliding window plan, while (b1) and (b2) show the VMAT plan. All distributions were normalized to the mean value of the region of interest 2 (ROI2, a circle with a radius of 10 pixels in Fig.4).

- The average DD and its standard deviation were 0.93 ± 1.28% and 0.60 ± 1.17% for the sliding window plan (Fig.9 (a1)) and the VMAT plan (Fig.9 (b1)), respectively.
- The gamma pass-rates were 93.6% and 95.6% for the sliding window plan (Fig.9 (a2)) and the VMAT plan (Fig.9 (b2)), respectively. Inconsistencies were seen in the low-dose region and located in the similar area in both plans. Those inconsistencies might be caused by the unexpected systematic errors depending on the system setup or the system itself.

CONCLUSIONS

The developed 4D dose distribution verification system successfully obtained the absorbed dose distribution from time-resolved images of the scintillation light emitted from the PS using a cooled CCD camera.

ACKNOWLEDGMENTS

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