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# Novel Three-Dimensional Dose Distribution Measurement System for Volumetric Modulated Arc Therapy

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## ABSTRACT

**Purpose:** This study aimed to develop a three-dimensional dose distribution measurement system using a plastic scintillator (PS), cooled charge-coupled device (CCD) camera, and electronic portal imaging device (EPID).

**Methods:** A prototype detector consisting of a cylindrical PS (20 cm in diameter and 15 cm in thickness), cooled CCD camera, and EPID was developed. When the PS was irradiated, scintillation light was emitted in proportion to the absorbed dose. The scintillation light was recorded using a cooled CCD camera set to 512 × 680 pixels, 16-bit grayscale, and 8.1 frames per second. This study evaluated the relationship between scintillation light intensity and absorbed dose, as well as the dependence on dose rate. Subsequently, static field and VMAT irradiations were performed using a 10 MV X-ray beam generated by TrueBeam. The three-dimensional light distribution was reconstructed by utilizing the scintillation light captured during irradiation, along with the fluence distribution obtained from the EPID. This reconstructed light distribution was then compared to the dose distribution calculated using a radiation treatment planning system.

**Results:** The relationship between scintillation light intensity and absorbed dose was linear. The variation in the scintillation light intensity was limited to 0.03% within the dose-rate range of 100-600 MU/min. The reconstructed light distribution closely resembled the calculated dose distribution. At the center of the static field irradiation, the mean dose difference and the gamma analysis pass rate, using the criteria of 3%/2 mm, were 0.40 ± 0.18% and 100%, respectively. For the VMAT irradiation, these values were -0.50 ± 0.26% and 97.5%, respectively.

**Conclusions:** The developed system facilitated precise measurement of three-dimensional dose distributions by capturing the scintillation light from the PS and the fluence distribution from the EPID.

## CONTACT

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## INTRODUCTION

- Intensity modulated radiation therapy (IMRT) requires delivery quality assurance (DQA) to ensure that treatment is accurate and safe.
- Currently, plan verification for IMRT involves the combined use of ionization chamber dosimeters, film, and two-dimensional semiconductor detector arrays; however, these methods have limitations, such as low detection sensitivity when errors occur outside the measurement cross-section.
- This problem can be resolved by performing plan verification based on three-dimensional dose distribution measurements.

## AIM

- To develop a three-dimensional dose distribution measurement system using a plastic scintillator (PS), cooled charge-coupled device (CCD) camera, and electronic portal imaging device (EPID).

## MATERIALS AND METHODS

**1. Measurement setup**

- We developed a prototype detector system which consisted of a cylindrical PS (20cm in diameter and 15 cm in thickness), cooled CCD camera and EPID (Fig.1).
- The scintillation light was recorded using a cooled CCD camera set to 512 × 680 pixels, 16-bit grayscale, and 8.1 frames per second.
- EPID images were recorded at a resolution of 720 × 526 pixels, with 8-bit grayscale and 25.0 frames per second.

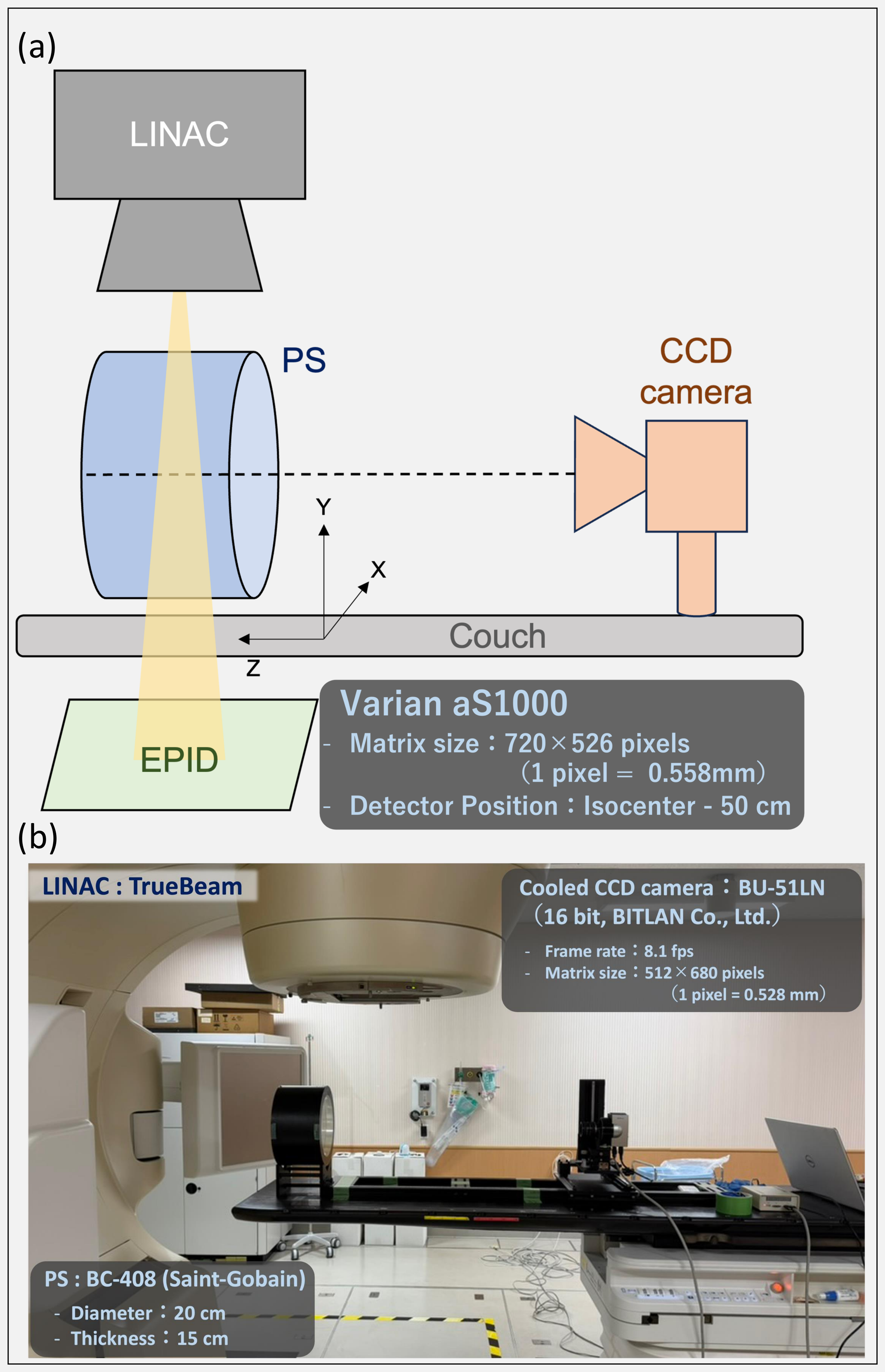


**Figure 1.** (a) a schematic diagram and (b) a photograph of the measurement setup. The PS was placed at a distance of 80 cm from the CCD camera. During all measurements, the experiments were conducted in a dark room.

**2. Preliminary measurement for scintillation light**

- Measurements were performed under the following irradiation conditions to characterize the preliminary properties of scintillation light, including its dose and dose-rate dependence.

  [Dose dependence]
  10MV, 10 cm × 2.5 cm, 0 - 600 MU, 600 MU/min
  [Dose-rate dependence]
  10MV, 10 cm × 2.5 cm, 100 MU, 100 - 600 MU/min

**3. Three-dimensional dose distribution reconstruction**

- The three-dimensional light intensity distribution was reconstructed using the images recorded for each frame and the dose fluence distribution along the z-axis obtained from the EPID image.
- Specifically, the reconstruction was performed by calculating the ratio of the reconstruction interval in the EPID dose profile to the entire irradiation range and applying this ratio to each frame (Fig. 2).

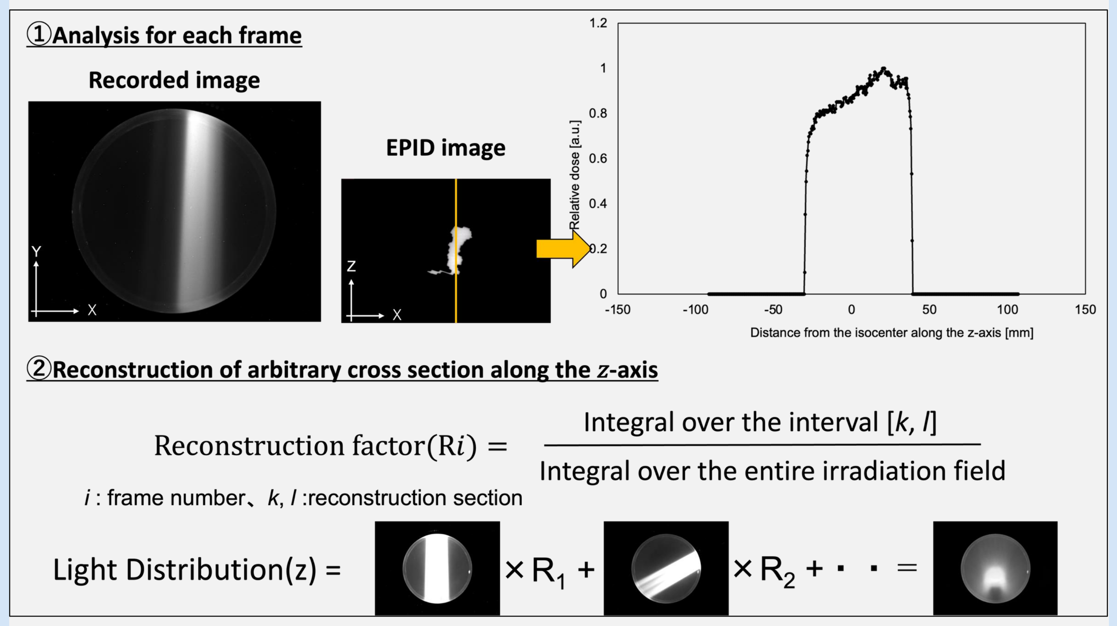


**Figure 2.** Schematic workflow of the three-dimensional dose distribution reconstruction. Because the dose profile along the z-axis depends on the x-coordinate, the weighting factor $R_i$ was determined for each x-position. The reconstruction interval can be adjusted to match the spatial resolution of the reference distribution for comparison.

- To evaluate the performance of the three-dimensional dose distribution reconstruction, a four-field irradiation was delivered using a TrueBeam LINAC with a 10-MV X-ray and a field size of 10 × 10 cm².
- The reconstructed distribution was compared with the dose distribution calculated by the treatment planning system (TPS; Eclipse version 18.1, Analytical Anisotropic Algorithm [AAA]).

## RESULTS and DISCUSSION

- The collected scintillation light intensity showed good linearity with the absorbed dose.
- The variation in the collected scintillation light intensity was within 0.03% over the dose-rate range of 100 - 600 MU/min, indicating negligible dose-rate dependence.

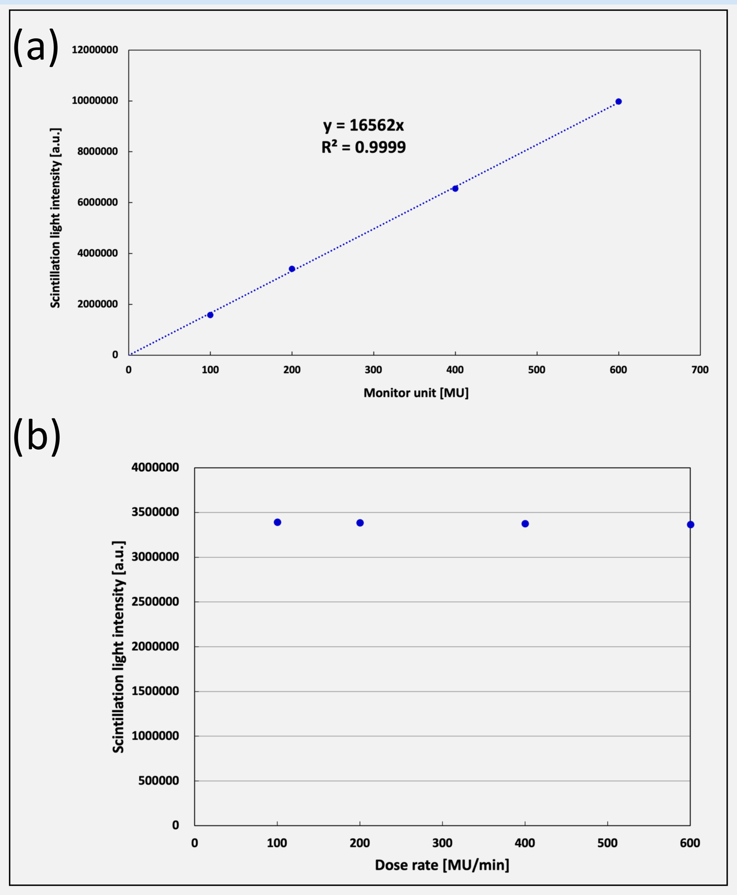


**Figure 3.** Dose dependence (a) and dose-rate dependence (b) of the scintillation light intensity. The analysis was performed using a 10 × 10 pixel ROI centered on the PS in the acquired images. The scintillation light intensity was quantified as the mean pixel value within the ROI.

- The reconstructed three-dimensional light intensity distribution and the three-dimensional dose distribution calculated by the TPS exhibited similar spatial distributions, as shown in Figure. 4(a) - (d), respectively.
- At the center of the static field irradiation, the mean dose difference and the gamma analysis pass rate, using the criteria of 3%/2 mm, were 0.40 ± 0.18% and 100%, respectively.
- For the VMAT irradiation, these values were -0.50 ± 0.26% and 97.5%, respectively.
- The analysis was performed for the region enclosed by the 30% isodose line.

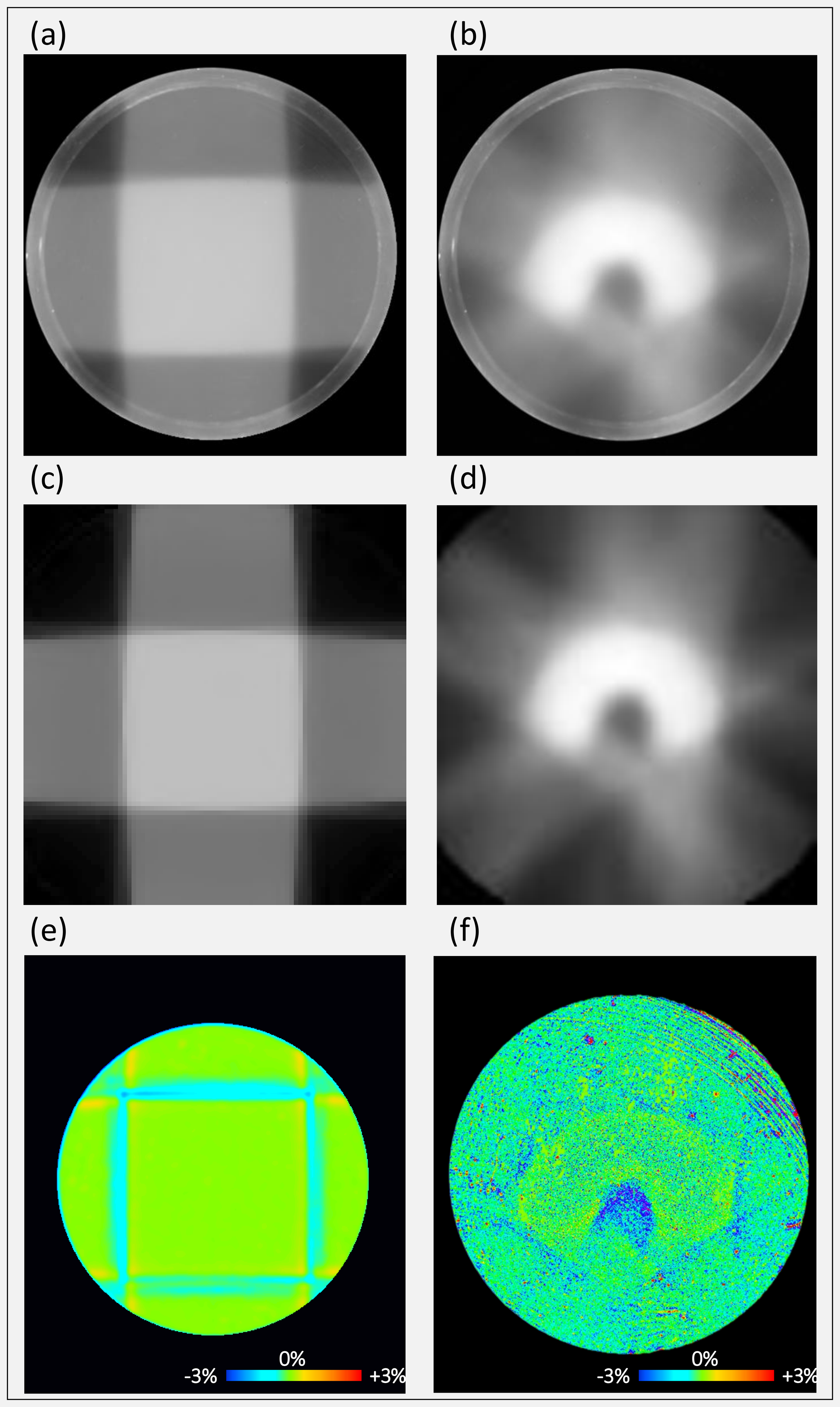


**Figure 5.** Axial distributions at the center of the irradiation field: (a) and (b) reconstructed three-dimensional scintillation light intensity distribution, (c) and (d) three-dimensional dose distribution calculated by the TPS, and (e) and (f) two-dimensional dose-difference distribution between the reconstructed and TPS-calculated distributions in the same plane. The analysis was restricted to the region receiving at least 30% of the maximum dose. Prior to comparison, the reconstructed distribution was corrected for the scattering of scintillation light within the PS using a double-Gaussian model.

## CONCLUSIONS

- The proposed system enables the reconstruction of a three-dimensional light intensity distribution by integrating two types of information acquired from the PS and EPID.
- Consequently, the reconstructed distribution can be directly compared with the three-dimensional dose distribution calculated by the TPS on arbitrary cross-sectional planes.

## ACKNOWLEDGMENT

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