Three-dimensional Isocenter Verification for Real-time Tumor-tracking Radiotherapy System Using a Reusable PVA-I Radiochromic Gel Dosimeter

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JULY 12–16 2020 VIRTUAL
JOINT AAPM | COMP MEETING
EASTERN TIME [GMT-4]

INTRODUCTION

A combined system comprising the Varian TrueBeam linear accelerator and a new real-time tumor-tracking radiotherapy system, SyncTraX (Shimadzu Co., Kyoto, Japan) can perform respiratory-gated radiotherapy[1]. The system uses a fiducial marker tracking technique using two color image intensifiers and X-ray tubes. Therefore, the three-dimensional (3D) isocenter tracking accuracy is particularly important. In a previous study, we developed a novel polyvinyl alcohol-iodide (PVA-I) radiochromic gel dosimeter that can be reused after annealing, unlike other existing gel dosimeters[2–4]. In this study, we investigated a 3D Winston–Lutz test as an isocenter verification for the SyncTraX system using a reusable gel dosimeter.

AIM

To evaluate the accuracy and usefulness of the 3D isocenter verification, an effective routine quality assurance (QA) for the SyncTraX system using a unique Winston–Lutz gel phantom comprising a reusable PVA-I radiochromic gel dosimeter.

METHOD

・The chemical compositions of the PVA-I gels are listed in Table 1.

・The prepared gels were poured into acrylic containers (2 cm × 2 cm × 12 cm), and a fiducial marker (2 mm diameter) was embedded in the gels, as shown in Fig. 1 (Winston–Lutz gel phantom).

・The gel phantoms were set to the QUASAR™ respiratory motion platform with a customized rotation stage moving in a 3D sinusoidal pattern (left–right [LR]: 3 mm peak-to-peak, superior–inferior [SI], and anterior–posterior [AP]: 20 mm peak-to-peak) with varying motion periods (3–5 s) (Fig. 2).

・The gel phantoms were irradiated with four MLC fields (1 cm × 1 cm) using the TrueBeam–SyncTraX system, when the marker position was within a ± 2 mm gating box (Figs. 3 and 4).

・In addition, the 3D isocenter verification under the same conditions (stable and 3D moving phantoms with a 4 s period) was repeated 30 times over six months by repeated annealing using a Winston–Lutz gel phantom. The annealing conditions were as follows: temperature of 45 ºC for 12 h in an incubator.

・Following irradiation, the gel phantoms were scanned from the front and lateral sides using a flatbed scanner (ES-10000G, Epson). The scan parameter was configured with 254 dpi (0.1 mm/pixel) and 48-bit RGB (16 bits per channel).

・The 3D displacements between the marker and radiation center were analyzed based on bilateral blue channel images extracted from the RGB images using an in-house MATLAB program.

METHOD

Table 1. Composition of PVA-I gels prepared in this study. Tribromoacetic acid (TBAA) as a sensitizer was added to standard PVA-I gels.

Base solution	
Water	98.6 wt%
Polyvinyl alcohol (PVA)	1.0 wt%
Gellan gun (GG)	0.4 wt%
Additives (M means mol/1000 gH_2O)	
Potassium iodide (KI)	100 mM
Fructose	100 mM
Tribromoacetic acid (TBAA)	2 mM

Fig. 1. Winston–Lutz gel phantom comprising PVA-I gels, which indicated red colorization upon irradiation and decolorization after annealing.

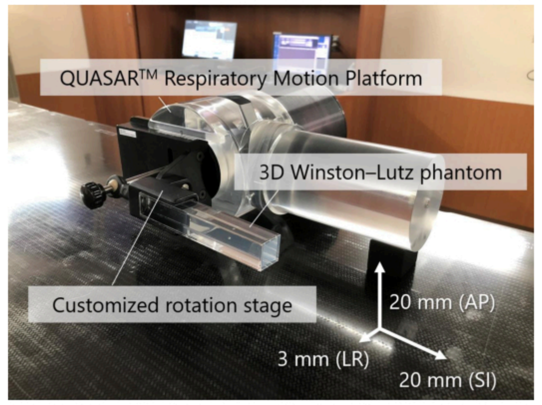

Fig. 2. QUASAR™ respiratory motion platform with a customized rotation stage. The Winston–Lutz gel phantom can be moved in a 3D sinusoidal pattern.

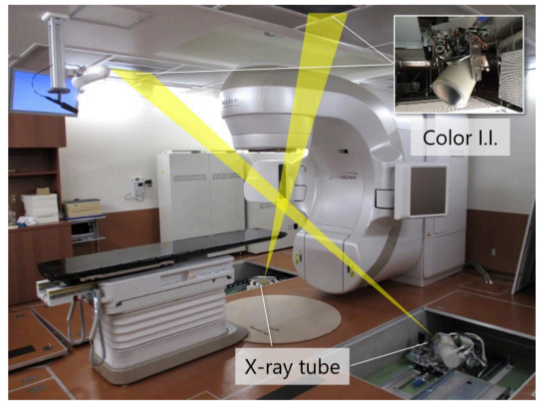

Fig. 3. Real-time tumor-tracking radiotherapy system, SyncTraX, combined with the Varian TrueBeam linear accelerator, which comprises two image intensifiers and X-ray tubes.

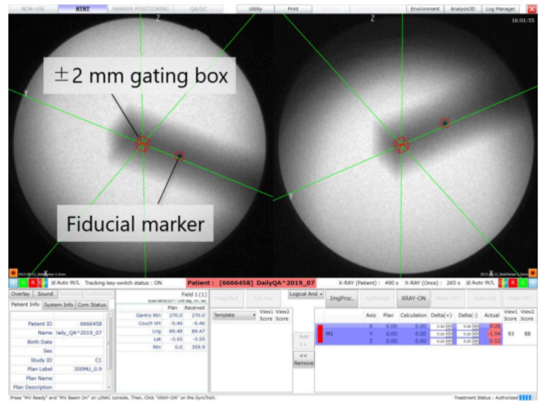

Fig. 4. Fluoroscopic images using SyncTraX system. When the fiducial marker was within a ±2 mm gating box, the beam was turned on.

RESULTS

Figure 4 shows the images of the irradiated Winston–Lutz gel phantoms scanned using a flatbed scanner. The gray images were obtained from blue channel images, and the irradiated regions and fiducial markers were clearly shown. The 3D isocenter displacements between the marker and radiation center obtained from the Winston–Lutz gel phantoms increased with the phantom motion velocity, and the average values were 1.35 (0.51–2.09), 1.04 (0.35–1.70), 0.85 (0.34–1.44), and 0.06 (0.01–0.18) mm for the 3D moving phantoms with periods of 3, 4, and 5 s, and stable phantom, respectively (Fig. 5). Regarding the 30–times–repeated 3D isocenter verification over six months, all results were within a ±2 mm gating box and excellent repeatability (1SD < 0.4 mm) was obtained, as evident by the results of 0.07 ± 0.04, 0.35 ± 0.12, and 0.23 ± 0.11 mm with stable phantom; and 0.31 ± 0.18, 1.09 ± 0.34, and 1.14 ± 0.15 mm with the 3D moving phantom in the LR, SI, and AP directions, respectively (Fig. 6).

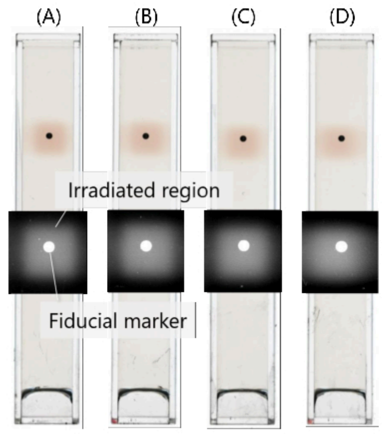

Fig. 5. Scanned images of irradiated Winston–Lutz phantoms using a flatbed scanner. Gray images were obtained from the blue channel images.
(A)(B): Stable phantom, (C)(D): 3D moving phantom,
(A)(C): Front images, (B)(D): Lateral images.

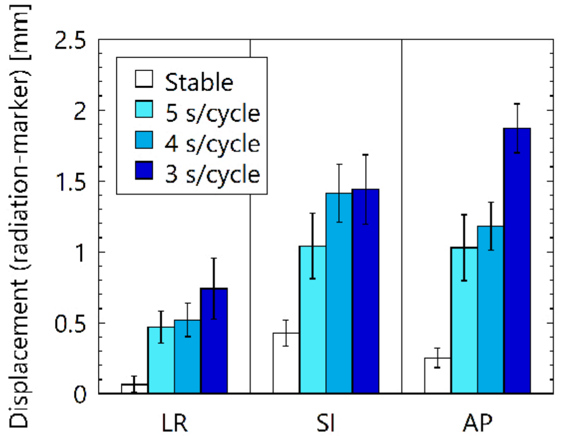

Fig. 6. Results of mean 3D isocenter displacements between the marker and radiation center in orthogonal directions evaluated from the 3D Winston–Lutz test with varying phantom motion velocities. Error bars indicate one standard deviation.

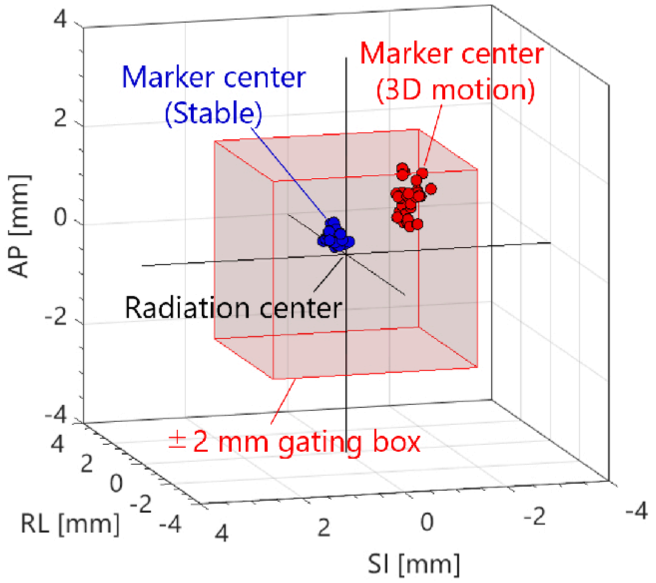

Fig. 7. Results of repeated 3D isocenter verification using Winston–Lutz gel phantom. The test was repeated 30 times over six months by repeated annealing. Red plots indicate results with 3D sinusoidal phantom motion; blue plots, without phantom motion.

CONCLUSIONS

The Winston–Lutz gel phantom, which comprises a reusable PVA-I gel dosimeter, can detect the 3D tracking accuracy of the TrueBeam–SyncTraX system easily and reliably. Additionally, it is useful for the routine QA of the system.

ACKNOWLEDGEMENTS

This work is supported by JSPS KAKENHI (Grant Number 17K09072).

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