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Dose–response measurement in gel dosimeter using various imaging modalities

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Abstract. Measurement methods that accurately measure radiation dose distribution in a three dimensional manner in order to allow comparisons of treatment plans are needed for quality assurance. One such measurement method involves the use of a polymer gel dosimeter to measure the dose distribution in three dimensions. During irradiation, a polymerization reaction makes new chemical bonds and induces changes of the chemical structure of the gel of the gel dosimeter. In the present study, dose–response measurement of an environment-friendly material used in the gel dosimeter was performed by imaging with computed tomography (CT) and R1, R2, and fluid-attenuated inversion-recovery (FLAIR) magnetic resonance imaging (MRI) under various imaging conditions. Dose–response characteristics in the gel dosimeter used in the experiment were observed at doses of 5–20 Gy administered by X-ray CT and MRI. Although the FLAIR signal was a relative value, the dose–response values with FLAIR were excellent compared to those with R1, R2, and CT. Determination of more appropriate imaging conditions could help expand the dose–response parameters of each measurement method.

1. Introduction

Recently, radiation dose distribution has become more complicated as attempts have been made to make radiation therapy more accurate [1]. Therefore, measurement and comparison of the three dimensions of dose distribution for the purpose of treatment planning is required for quality assurance. One measurement method uses a polymer gel dosimeter to measure the three dimensions of dose distribution [1-4]. During irradiation, a polymerization reaction changes the chemical structure of the gel in the gel dosimeter. The extent of polymerization varies with dose. Development of a dose evaluation technology that utilizes X-ray computed tomography (CT) and magnetic resonance imaging (MRI) parameters is necessary for clinical use of the gel dosimeter [1, 5, 6].

In the present study, dose–response characteristics of an environment-friendly gel dosimeter composed of less toxic monomers and polysaccharide gel were evaluated by use of CT and MRI imaging.

2. Materials and Methods

2.1. The gel dosimeter

The gel dosimeter was prepared as follows. A mixture of deacylated gellan gum (0.4 g) and ultrapure water (49.6 g) was heated at about 95°C to dissolve completely the deacylated gellan gum. The aqueous solution was cooled slowly until 40°C, and then mixed with monomer solutions consisting of 2-hydroxyethyl methacrylate (2.0 g), triethylene glycol monoethyl ether monomethacrylate (2.0 g), polyethylene glycol 400 dimethacrylate (2.0 g), tetrakis hydroxymethyl phosphonium chloride (0.11 g), glucono delta-lactone (0.36 g), and ultrapure water (43.53 g). The mixed solutions were transferred into a plastic bottle before getting cold. The bottles were vacuum-packed, and then stored overnight in a refrigerator to get the gel dosimeter used in this work.

2.2. Irradiation method and conditions

The gel dosimeter was irradiated with 10-MV X-rays using EXL-15SP (Mitsubishi Electric Corporation). The gel dosimeter was arranged at the center of the 10 cm × 10-cm irradiation field in a water phantom. The source–surface distance was adjusted to 90 cm and the source–detector distance to 100 cm. Dosimeters were irradiated at 0 to 60 Gy. The gel dosimeter temperature was maintained in a refrigerator.

2.3. X-ray CT device

The ECLOS (Hitachi Medico Corporation) was used. The tube voltage was 120 kV, beam current was 300 mA, and scan time was 3.0 seconds per 1 rotation. Slice thickness was 10 mm.

2.4. MRI device

EXCELART vantage 1.5-T (Toshiba Medical Corporation) was used. A quadrature detection knee coil was used for data acquisition. The slice thickness was 5 mm. T1 and T2 values and fluid-attenuated inversion-recovery (FLAIR) images of samples were analyzed.

To measure T1 values, repetition time (TR) was set to 6000 msec and echo time (TE) was set to 10 msec. Inversion time (TI) was varied at 100, 300, 500, and 1000 msec. The reciprocal of the obtained T1 value was assumed to be R1.

To measure T2 values, TR was set to 2000 msec and TE was set to 30, 60, and 120 msec. The reciprocal of the obtained T2 value was assumed to be R2.

To measure signal intensity of FLAIR images, TR was set to 1400 msec and TE was set to 105 msec. TI was varied at 1000, 1500, 2000, 2500, and 3000 msec.

3. Results

3.1. X-ray CT device

The scanned CT image is shown in Figure 1. Figure 2 shows the radiation dose and the response characteristics. Linearity was observed from 5 to 20 Gy. The polymerization reaction became saturated as the dose approached 40 Gy, as indicated by the plateau in CT values at 40 Gy and above.

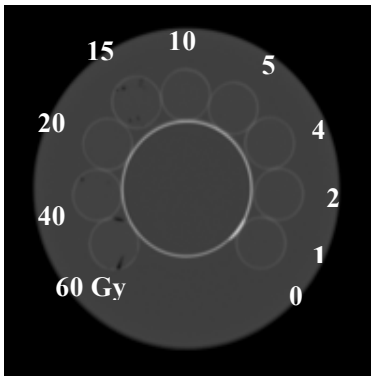

Figure 1: Computed tomography image of the gel.

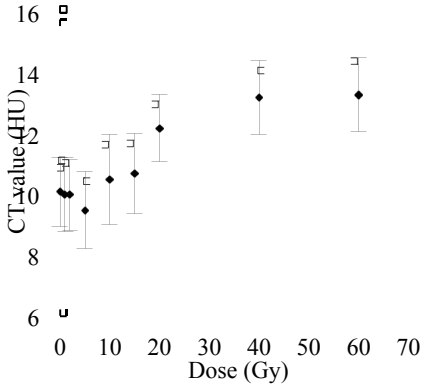

Figure 2: Dose–CT value response characteristics of the gel.

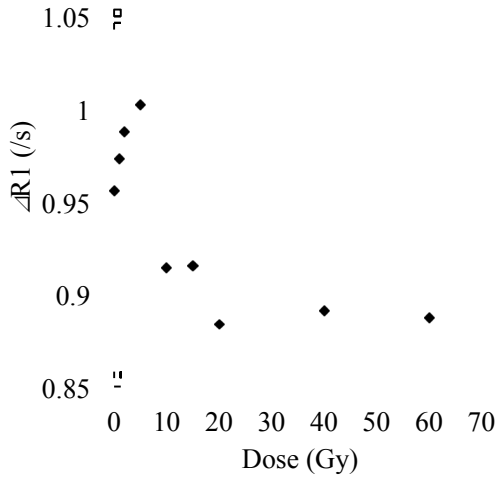

Figure 3: Dose-R1 response curve of the gel.

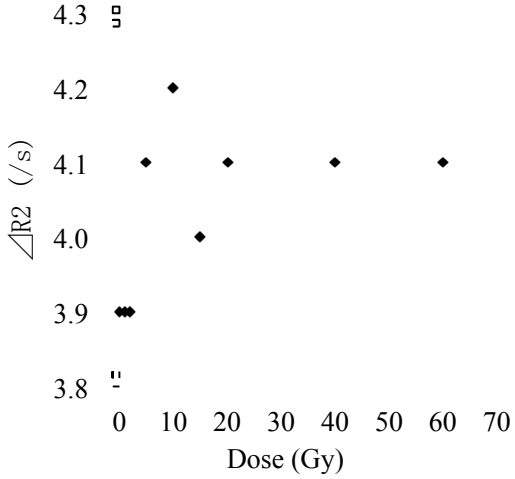

Figure 4: Dose-R2 response curve of the gel.

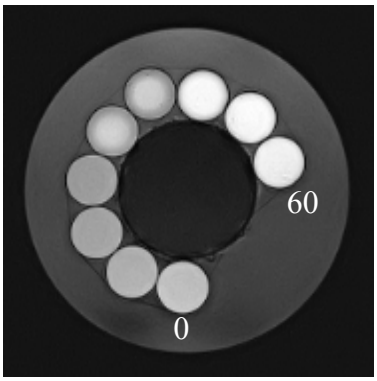

Figure 5: FLAIR image at TI = 1500 msec.

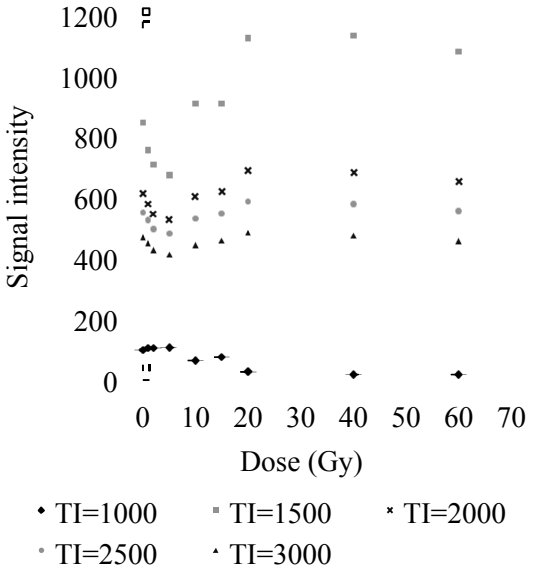

Figure 6: Dose-FLAIR signal intensity response curve of the gel.

4. Discussion

4.1. Comparison by modality

Use of CT rather than MRI allowed the measurement time to be reduced from several minutes to just a few seconds. Compared to MRI, advantages of CT include high spatial resolution and less image distortion. On the other hand, protons were measured by MRI because changes resulting from the polymerization reaction could be more clearly described compared with CT. Although the result of FLAIR was a relative value, the dose–response values were excellent compared with R1, R2, and CT dose–response values. However, calibration is necessary for comparative assessment because FLAIR, in which evaluation by one sequence is possible, can shorten the total imaging time compared with R1 and R2 measurements.

4.2. Accuracy management of the gel dosimeter

To improve measurement precision of the gel dosimeter, accuracy control of the dosimeter is important. Accuracy management involves prevention of oxygen exposure, temperature management, measurement receptacle maintenance, shading of ultraviolet light, and accuracy of mixing, and it is necessary for experimental reproducibility. The gel dosimeter should be shaded to prevent anomalous activation of the polymerization reaction, which can be activated not only by ionizing radiation but also by ultraviolet light. However, shading coupled with exposure to oxygen weakens the polymerization reaction. This effect is gradually diminished by the deoxygenator contained in the gel dosimeter. Therefore, when the gel dosimeter is prepared, it is necessary to irradiate it ahead of time.

5. Conclusion

Dose–response characteristics in the gel dosimeter used in the experiment were observed at doses of 5–20 Gy administered by X-ray CT and MRI. Identification of more appropriate imaging conditions to expand the dose–response characteristics of each measurement method would be highly desirable. Because environmental and technical factors can greatly affect reproducibility, accuracy management of the gel dosimeter is also important.

6. References

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