Comparison between polymer gel dosimetry and calculated dose with small field in stereotactic irradiation

H Kawamura1,2, K Shinoda3, H Fuse4, T Terunuma2,4, K Miyamoto3, T Sakae2,4, and A Matsumura2
1Department of Radiological Sciences, Ibaraki Prefectural University of Health Sciences, 4669-2, Ami, Ami-machi, Inashiki-gun, Ibaraki, Japan
2Graduate School of Comprehensive Human Science, University of Tsukuba, 1-1-1, Tennodai, Tsukuba, Ibaraki, Japan
3Tsukuba Medical Center hospital, 1-3-1, Amakubo, Tsukuba, Ibaraki, Japan
4Proton Medical Research Center, University of Tsukuba, 2-1-1 Amakubo, Tsukuba, Ibaraki, Japan

E-mail: kawamura@ipu.ac.jp

Abstract. The purpose of this study is to investigate gel dosimetry for a small irradiation field in stereotactic radiotherapy. Treatment plans were generated by the Pinnacle3 treatment plan system (TPS) for three different circular irradiated fields: 10 mm, 15 mm, and 20 mm. The polymer gels were irradiated to 6 Gy with 10-, 15-, and 20-mm-diameter collimators in 4 MV photon beams for stereotactic irradiation following TPS. Irradiated gels were evaluated with MRI at 1.5 T with R2 images. Firstly, the line profile of the irradiated center between TPS plan and R2 image was compared. In the center profile at a dose calculated from the treatment plan, the full width at half maximum (FWHM) of 10-mm, 15-mm, and 20-mm collimators, were 13 mm, 19 mm, and 25 mm, respectively. In the center profile at R2 from the gel dosimetry, the FWHM were 13 mm, 20 mm, and 23 mm, respectively. Secondly, R2 images were converted to dosimetric maps to apply the gamma evaluation method. Comparison using gamma evaluation in the center of the irradiated plane between TPS plan and the dose map from the R2 image was performed. In gamma evaluation, when 3% and 3 mm criteria were used for comparison of the center plane of dose image from TPS and gel dosimetry, the pass ratio of the gamma criterion between calculated dose from the TPS and the dose map of irradiated gels in stereotactic irradiation was 98.6%. In comparison of the center profile and center plane, results of gel dosimetry were shown to have good agreement with the generated treatment plan dosimetric map for stereotactic irradiation.

1. Introduction
Polymer gel dosimetry that utilizes radiation-induced polymerization that is related to radiation dose, is a three-dimensional (3D) dosimetric tool for quality assurance [1-3][1]. Polymer gel dosimetry is desirable for radiation therapy for dose validation and to check whether the planned dose and areas are correctly irradiated [4]. It can be used to measure 3D doses in conformal radiotherapy, and it is efficient at measuring the 3D dose distribution in radiation therapy. Additionally, it has advantages of water and soft-tissue equivalent material dosimeters [5, 6][2, 3]. When a polymer gel is used as a phantom, it is possible to measure the radiation dose without disturbing the radiation fields and
surroundings [7-9][4-6]. Accordingly, polymer gel dosimetry is a more suitable method than dosimetry using ion chambers for a small irradiated field.

Contemporary radiotherapy treatments include intensity modulated radiotherapy (IMRT) and stereotactic radiotherapy (SRT) applied to irradiate complicated targets and small targets. These treatment techniques need to employ 3D dosimetry to accurately deliver a treatment dose to a clinical target. In IMRT, in order to irradiate a clinical target more accurately following Treatment Planning System (TPS) for irradiation, the irradiated field is changed with a multi-leaf collimator and dose rate adjustment. However, it is difficult to evaluate accuracy with polymer gel dosimetry in IMRT. Because the polymer gel dosimetry is dependent on dose rate, it was also necessary to evaluate 3D dose distributions irradiated with a constant dose rate in the present study. In this way, polymer gel dosimetry could be improved to use IMRT irradiation.

Polymer gel dosimetry can also be used in small field irradiation. The purpose of the present study is to investigate gel dosimetry for a small irradiation field in stereotactic radiotherapy. Comparisons between polymer gel dosimetry and calculated dose from the TPS were performed in the center profile and the center plane. The gamma evaluation method was used for comparison in the center plane.

2. Materials and Methods

2.1 Preparation of polymer gel
A BANG-3 type polymer gel was prepared. The BANG kit was melted in a hot water bath at 55 degree, and 5 μM CuSO4 as modifying buffer and 1 mM ascorbic acid as antioxidant agent were added. Prepared gels were poured into polyethyleneterephthalate (PET) containers. The PET tubes were 30 mm in diameter and 70 mm in length for dose-R2 calibration. The PET containers were 50 mm, 50mm, and 70 mm in length for SRT irradiation (Fig. 1). The PET containers were filled with ascorbic acid solutions 2 days before gel preparation for the purpose of oxygen scavenging. The gels in PET containers were stored wrapped in aluminum foil in a refrigerator at 4 degree until irradiation.

2.2 Gel phantom design of stereotactic irradiation and treatment plan
Figure 1(a) shows a gel phantom for SRT irradiation. The phantom was a 200×140×125 mm Styrofoam container within the gel. The phantom was filled with water and air was turned out.

Treatment plans were 1.0-mm, 1.5-mm, and 2.0-mm simple circular irradiated fields generated by the Pinnacle treatment plan radiotherapy system made by the Hitachi Medical Corporation. An X-ray CT device (CTS-20SPS, Shimadzu Corporation) was used for the stereotactic irradiation treatment plan. A non-helical scan was employed. The CT exposure conditions were as follows: a tube voltage of 120 kV, tube current of 130 mA, exposure time of 1.0 s and a slice thickness of 3.0 mm, an imaging field of view of 300×300 mm. The number of slices of the CT images was 30.

Figure 1: (a) left: Photograph of phantom including polymer gels; (b) middle: photograph of CT acquisition with phantom including gel acquisition treatment plan; (c) right: calculated dose map of treatment plan procedure from the acquired CT images. The red line shows the center profile.
2.3 Irradiation of prepared gels for calibration and for stereotactic irradiation
Prepared gels were irradiated with a photon beam at the Tsukuba Medical Center hospital using Linac (EXL-15DP, Mitsubishi Electric Corporation). The polymer gels in the PET tubes was irradiated with 4 MV photon beams (with no collimator) at the isocenter in a 300×300×300 mm³ water tank for calibrations of dose versus R2 from 0 to 10 Gy in the beam axis. The phantom including the polymer for SRT was irradiated with 4 MV photon beams (with 10-, 15-, and 20-mm collimators, respectively) at the isocenter of a 300×300×300 mm³ water tank to 6 Gy for SRT irradiation from the generated TPS plans in the beam axis. These gels after irradiation were stored in a refrigerator at 4 degree until MRI at 1.5 T.

2.4 MRI measurements of irradiated gels
MRI measurements were performed on a 1.5 Tesla TOSHIBA EXCELART Vantage scanner 1 day after irradiation. Irradiated gels were scanned with a quadrature (QD)Torso SPEEDER coil.

The gel was imaged using a multi spin echo pulse sequence (with a first effective echo time, TE1=30 ms, followed by TE2=60 ms). For each scan a repetition time of 4000 ms was used in order to reduce the influence of spin-lattice relaxation, with a 1 mm² resolution, and 5-mm-thick planes. The R2 images were calculated from two different echo time images using an in-house program.

2.5 Comparison in the center profile and in the center plane using gamma evaluation between gel measurements and calculated from the TPS
The R2 image in the center profile and the dosimetric map in the center plane of irradiated gels were compared with calculated data from TPS with three different fields. The R2 images were normalized in order to compare the calculated profile from TPS.

For comparison in the center plane, the R2 images of polymer gels were converted with a dosimetric map using R2 versus dose calibration curve at the center plane. The dosimetric map from irradiated gels and calculated dose map from TPS were compared in the central plane using gamma evaluation with DD system software (R-TECH INC) [10][7].

3. Results and Discussion

3.1 Calibration of dose response of polymer gel in photon beams and Linearity of R2 versus dose
The R2 calibration curve as a function of photon doses between 0 and 10 Gy was linear with regard to dose. The data points were obtained by averaging R2 values in the polymer gel. The fitted straight line had a slope of 1.99 (Gy⁻¹·s⁻¹) and an intercept of 11.6 (s⁻¹). The coefficient of correlation was 0.996.

3.2 Comparison profile between gel measurements and TPS
Figure 2(a) shows the photograph of the non-irradiated polymer gel and SRT irradiated gels with 10-mm, 15-mm, and 20-mm collimators.

The comparison profiles in the center line between R2 from gels and calculated dose from TPS showed good agreement (Fig. 2(b-d)). In the center profile at the calculated dose from the treatment plan, the full width at half maximum (FWHM) of 10-mm, 15-mm, and 20-mm collimators were 13 mm, 19 mm, and 25 mm, respectively. In the center profile at R2 from the gel dosimetry, the FWHM of 10-mm, 15-mm, and 20-mm collimators were 13 mm, 20 mm, and 23 mm, respectively. The results between gel dosimetry and calculated dose in the central profile for SRT irradiation showed good agreement.

3.3 Comparison in the center plane between gel measurements and TPS using gamma evaluation
The pass-fail criterion for gamma evaluation method included a dose difference of 3% and a distance to agreement of 3 mm. In the case of SRT irradiation with a 10-mm collimator, the pass ratio of the gamma evaluation between calculated dose from the treatment plan and the dose map of the gel
dosimetry in stereotactic irradiation was 98.6%. The results of gamma evaluation in the central plane showed good agreement between the dose map from gel dosimetry and calculated dose from TPS. A region with partial disagreement of the gamma evaluation method was seen with a low dose. This disagreement could have been caused by phantom size and uncertainty of the R2-dose conversion procedure. The isodose map shows the agreement with the high dose region in the center plane.

4. Conclusions
This study showed good agreement between gel dosimetry and the generated treatment plan dosimetric map in the center of the profile and plane in stereotactic irradiation. In small field photon dosimetry, polymer gels can be an effective tool for comparison of the methods of gel dosimetry and generated calculated plans [11, 12].

5. References
[1] Baldock C et al 2010 Phys. Med. Biol. 55 R1-63
[2] Hill B et al 2005 Br. J. Radiol. 78 623-30
[3] Murry P and Baldock C 2000 Australas. Phys. Eng. Sci. Med. 23 44-51
[4] Lepage M et al 2002 Phys. Med. Biol. 47 1881-90
[5] Keall P and Baldock C 1999 Australas. Phys. Eng. Sci. Med. 22 85-91
[6] Venning A J et al 2005 Med. Phys. 32 1047-53
[7] Baldock C et al 1998 Phys. Med. Biol. 43 695-702

Figure 2: (a) upper left: photograph of irradiated polymer gels in stereotactic irradiation with 10-mm, 15-mm, and 20-mm collimators (left to right); (b) upper right: comparison between gel dosimetry and calculation from TPS in the center profile with SRS using 10-mm collimator; (c) lower left: comparison between gel dosimetry and calculation from TPS in the center profile with SRS using 15-mm collimator; (d) lower right: comparison between gel dosimetry and calculation from TPS in the center profile with SRS using 20-mm collimator.
[8] Pappas E et al 2008 Med. Phys. 35 4640-8
[9] Novotný J et al 2002 Radiother Oncol. 63 223-30
[10] Low D A et al 1998 Med. Phys. 25 656-61
[11] Rintoul L et al 2003 Appl. Spectrosc. 57 51-7
[12] Lepage M et al 2002 Phys. Med. Biol. 47 1881-90