Journal of Physics: Conference Series **573** (2015) 012068 doi:10.1088/1742-6596/573/1/012068

Polymer gel dosimetry for neutron beam in the Neutron Exposure Accelerator System for Biological Effect Experiments (NASBEE)

H Kawamura[1], H Sato[1], T Hamano[2], M Suda[3] and H Yoshii[4]
[1]Department of Radiological Sciences, Ibaraki Prefectural University of Health Sciences, 4669-2, Ami, Ami-machi, Inashiki-gun, Ibaraki, Japan
[2]Research Center for Charged Particle Therapy, National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage-ku, Chiba, Japan
[3]Research, Development and Support Center, National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage-ku, Chiba, Japan
[4]Research Center for Radiation Emergency Medicine, National Institute of Radiological Sciences, 4-9-1 Anagawa, Inage-ku, Chiba, Japan

E-mail: kawamura@ipu.ac.jp

Abstract. This study aimed to investigate whether gel dosimetry could be used to measure neutron beams. We irradiated a BANG3-type polymer gel dosimeter using neutron beams in the Neutron exposure Accelerator System for Biological Effect Experiments (NASBEE) at the National Institute of Radiological Sciences (NIRS) in Japan. First, the polymer gels were irradiated from 0 to 7.0 Gy to investigate the dose-R_2 responses. Irradiated gels were evaluated using 1.5-T magnetic resonance R_2 images. Second, the polymer gels were irradiated to 1.0, 3.0, and 5.0 Gy to acquire a depth-R_2 response curve. The dose-R_2 response curve was linear up to approximately 7 Gy, with a slope of 1.25 $Gy^{-1}\cdot s^{-1}$. Additionally, compared with the photon-irradiated gels, the neutron-irradiated gels had lower R_2 values. The acquired depth-R_2 curves of the central axis from the 3.0- and 5.0-Gy neutron dose-irradiated gels exhibited an initial build-up. Although, a detailed investigation is needed, polymer gel dosimetry is effective for measuring the dose-related R_2 linearity and depth-R_2 relationships of neutron beams.

1. Introduction

Radiotherapy techniques have been applied to intensity-modulated radiotherapy (IMRT), stereotactic radiotherapy (SRT), and particle therapy. Although these therapies produce better dose distributions than conventional techniques, in particle therapies such as proton therapy and carbon therapy, energetic protons and carbon ions generate neutrons upon interaction with collimators, and the generation of secondly neutron radiation cannot be avoid. Patients receiving these therapies as well as technicians and surrounding staff are exposed to secondly neutron radiation from the collimators and patients. Younger patients who are exposed to such radiation and thus to extra radiation treatment doses cannot be ignored.

Polymer gels are 3-dimensional (3D) dosimetric tools used to evaluate radiation dose-related radiation-induced polymerization [1-4]. Therefore, polymer gel dosimetry is desirable for radiation therapy. Additionally, this technique features the advantages of water and soft-tissue equivalent material dosimeters. When using a polymer gel as a phantom, it is possible to measure the radiation dose without disturbing the radiation fields and surrounding areas.

Polymer gel dosimetry of radiation beams with contributions from neutron [5-7] and carbon ion [8] have been previously reported. Further work dose need to be undertaken to calibrate the response of the gel to neutron beams and high linear energy transfer (LET) particles.

The purpose of the present study was to investigate whether polymer gels were available to measure the generated neutron-beam radiation doses in radiotherapy.

2. Materials and Methods

2.1 Preparation of polymer gel

A BANG-3 type polymer gel was prepared. The BANG kit (MGS Research Inc. Guilford, CT, USA) was melted in a hot water bath at 55°C, and a modifying buffer and an antioxidant agent were added. Prepared gels were poured into polyethyleneterepthalate (PET) containers of 30 mm × 30 mm × 65 mm for dose-R_2 calibration and 40 mm × 40 mm × 150 mm for depth-R_2 response curve acquisition. These containers had been filled with an ascorbic acid solution 2 days before gel preparation for the purpose of oxygen scavenging [9]. The gels in the containers were wrapped in aluminium foil and stored in a refrigerator at 4°C until irradiation.

2.2 Irradiation field of neutron beams and set up

The prepared gels were irradiated with a neutron beam in Neutron-exposure Accelerator System for Biological Effect Experiments (NASBEE) at the National Institute of Radiological Sciences (NIRS) in Japan. This facility was developed to study the biological effects of neutrons [10]. The neutron was produced by 4 MeV deuterons bombarding into the beryllium target. The neutron energy spectrum revealed a mean energy of 2.0 MeV. In this facility, the beam gantry was set in the vertical direction.

2.3 Irradiation of prepared gels for calibration and for stereotactic irradiation

The prepared gels were placed upside-down 240 mm below the surface with the longitudinal axis placed in the beam axis for the dose-R_2 response measurements and depth-R_2 measurements. For the dose-R_2 response measurements, the polymer gels were set in the central axis, three plastic 10-mm-thick phantoms were placed on the prepared gels, and plastic phantoms surrounded the prepared gels. The prepared gels were irradiated to calibrate the dose versus R_2 from 0 to 7.0 Gy. For the depth-R_2 measurements, a 150-mm-length polymer gel was inserted parallel to the beam axis in a plastic phantom. The three 10-mm-thick plastic phantoms on the prepared gels were removed from the beam line [figure 1 (a)]. The prepared gels were irradiated to 1.0, 3.0, and 5.0 Gy for the depth-R_2 examination. After irradiation, these gels were stored in a refrigerator at 4°C until 1.5-T magnetic resonance imaging (MRI).

2.4 Irradiation for photon beams and set up

For comparison of the sensitivity of the gel for neutron, prepared gels were irradiated with a 10 MV X-ray (photon) beam on a linear accelerator (EXL-15SP, MITSUBISHI, Japan) at Ibaraki Prefectural University of Health Sciences. The gels in PET container were irradiated with 1.0, 3.0, and 5.0 Gy at the isocenter at a depth of 5 cm in a 300×300×300 mm^3 water tank. The dose rate was 4 Gy/min.

2.5 MRI measurements of irradiated gels and Analysis

MRI measurements were performed on a 1.5-T Toshiba Excelart Vantage scanner (Toshiba Medical Systems, Tochigi, Japan) 4 days after irradiation. The irradiated gels were scanned with a quadrature (QD) Torso SPEEDER coil (Toshiba Medical Systems). The gels were set in the coil and imaged using a multi-spin echo pulse sequence [with a first effective echo time (TE1) =30 ms and second effective TE (TE2) = 60 ms]. For each scan, a repetition time of 4000 ms was used to reduce the influence of spin-lattice relaxation along with a 1-mm^2 resolution, and 5-mm-thick planes. The R_2

image was calculated from two different echo time images using an in-house program [11]. For the dose-R_2 response measurements, regions of interest (ROI) were drawn in the R_2 images, and the mean values and standard deviations of ROI were measured. The depth-R_2 profiles were evaluated from the R_2 images in the central axis profile.

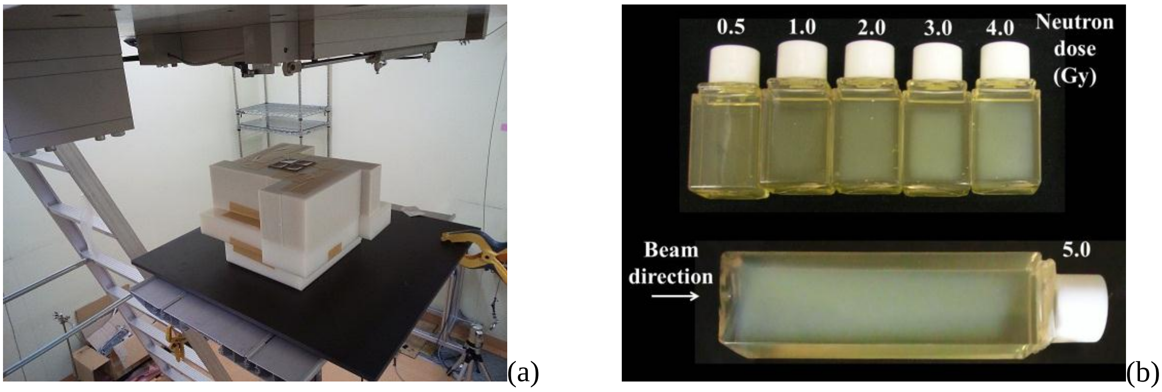

Figure 1. (a) Photograph showing the gel phantom set-up for the depth-R_2 distribution experiments with a neutron beam in NASBEE at NIRS. (b) Upper: 0.5, 1.0, 2.0, 3.0 and 4.0 Gy-irradiated gels (left to right) for the dose-R_2 response measurements; lower: 5.0 Gy-irradiated gel for the depth-R2 measurements. The gel for the depth-R2 measurement was exposed from left to right direction (arrow).

3. Results and Discussion

3.1 Neutron-beam dose-response curve of the polymer gel and R_2 versus dose linearity

A photograph of the neutron beam-irradiated gels is shown in figure.1 (b). The results indicated visual dose-related change in polymerization. The R_2 response curve as a function of the neutron dose from 0 to 7 Gy was linear related to the dose [figure 2 (a)]. The data points were obtained by averaging the R_2 values in the polymer gel ROI at the same dose. The fitted straight line had a slope of 1.25 $Gy^{-1} \cdot s^{-1}$, intercept of 6.29 s^{-1}, and correlation coefficient of 0.984.

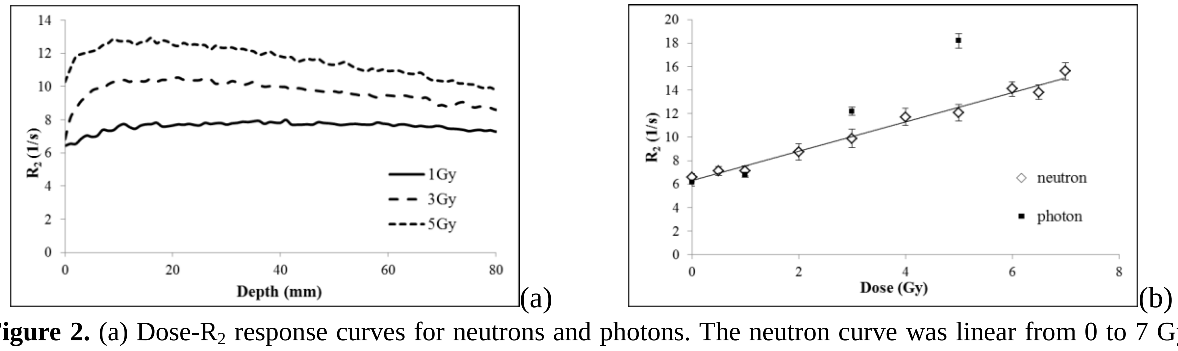

Figure 2. (a) Dose-R_2 response curves for neutrons and photons. The neutron curve was linear from 0 to 7 Gy. (b) Depth-R_2 dose distributions for 1-, 3-, 5-Gy neutron irradiation were shown.

For comparison, the photon-irradiated gels; the R_2 value of irradiated gels with 3- and 5-Gy photon beams were higher than those of gels irradiated with identical neutron beams [figure 2 (a)]. It was difficult to measure the dose from neutron alone because photons and other particles developed when the neutrons impinged on the gels and plastic phantoms. Additionally, neutron have high LET and relative biological effectiveness; therefore, the sensitivity of polymer gel to neutrons is possibly lower than the sensitivity to photon, as same as proton and carbon [12]. The result in figure 2 (a) will require further investigation.

3.2 Depth-R_2 profiles between gel measurements

Figure 2 (b) shows the depth-R_2 profiles in the central axis line of the 1.0-, 3.0- and 5.0-Gy- irradiated gels. The curves obtained at 3.0 and 5.0 Gy revealed an initial R_2 build-up at a shallow depth. This build-up was caused by the increasing gamma rays resulting from the interactions of the neutrons with the gels and surrounding plastic phantoms. This curve decreased with the gel depth. The R_2 values at identical depths were increased with higher neutron doses.

4. Conclusions

This study revealed a linear neutron dose-R_2 response curve. Therefore the polymer gel dosimetry can be used for neutron measurements. The polymer gel depth-R_2 curve in response to neutron beam irradiation indicated an initial build-up and reduction in depth-R_2 curves with increasing depth. The neutron beam depth-dose curve can be more effectively acquired with polymer gels than with other dosimetry tools. Further investigation will be needed to evaluate the effects of neutrons, photons and the other particles.

5. Acknowledgement

The authors would like to acknowledge the staff of NIRS for help with the experiments using neutron beams. This work was supported in part by JSPS KAKENHI Grant Number 24601012.

6. References

[1] Baldock C *et al* 2010 *Phys. Med. Biol.* **55** R1-63
[2] Mather M L *et al* 2003 *Ultrasonics* 41 551-9
[3] Venning A J *et al* 2004 *J. Phys.: Conf. Ser.* **3** 155-8
[4] Baldock C 2006 *J. Phys.: Conf. Ser.* **56** 14-22
[5] Uusi-Simola J et al 2003 *Phys. Med. Biol.* **48** 2895-906
[6] Farajollahi A R *et al* 2000 *Phys. Med. Biol.* **45** N9-14
[7] Vanossi E *et al* 2008 *Radiat. Meas.* **43** 442-5
[8] Ramm U *et al* 2000 *Phys. Med. Biol.* **45** R95-102
[9] Murakami Y *et al* 2007 *Phys. Med. Biol.* **52** 2301-11
[10] Takada M *et al* 2011 *AIP Conf. Proc.* **401** 1336
[11] Kawamura H *et al* 2013 *Appl. Radiat. Isot.* **77** 94-102
[12] Heufelder J *et al* 2003 *Med Phys.* **30** 1235-40