

A study on the reproducibility and spatial uniformity of N-isopropylacrylamide polymer gel dosimetry using a commercial 10X fast optical-computed tomography scanner

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Abstract. This study investigated the reproducibility and spatial uniformity of N-isopropylacrylamide (NIPAM) polymer gel as well as the reproducibility of a NIPAM polymer gel dosimeter. A commercial 10X fast optical computed tomography scanner (OCTOPUS-10X, MGS Research, Inc., Madison, CT, USA) was used as the readout tool of the NIPAM polymer gel dosimeter. A cylindrical NIPAM gel phantom measuring 10 cm (diameter) by 10 cm (height) by 3 mm (thickness) was irradiated by the four-field box treatment with a field size of 3 cm × 3 cm. The dose profiles were found to be consistent at the depths of 2.0 cm to 5.0 cm for two independent gel phantom batches, and the average uncertainty was less than 2%. The gamma pass rates were calculated to be between 94% and 95% at depths of 40 mm for two independent gel phantom batches using 4% dose difference and 4 mm distance-to-agreement criterion. The NIPAM polymer gel dosimeter was highly reproducible and spatially uniform. The results highlighted the potential of the NIPAM polymer gel dosimeter in radiotherapy.

1. Introduction

The development of three-dimensional (3D) polymer gel dosimetry and fast dose readout tools has slowly progressed in recent decades [1, 2]. Complex chemical reactions and interactions among gel compositions occur during the radiation-induced polymerization process [3-5]. Thus, the dose-response characteristics of polymer gels vary [7]. The temperature program of the gel-preparation process also affects the gel sensitivity because of the exothermal polymerization reaction of the polymer gel [8, 9]. The adoption of appropriate readout tools with the corresponding calibration gel dosimetry method is also important in obtaining accurate 3D dose distribution [11-14]. According to a previous study [12], the sources of uncertainty are as follows: (1) digitalization and electronic noise in the data acquisition system, (2) mechanical and optical source variation, (3) gel uniformity, and (4) reconstruction algorithm. In the present study, N-isopropylacrylamide (NIPAM) polymer gel was used with a commercial 10X fast optical-computed tomography (CT) scanner to evaluate the uncertainties in polymer gel dosimetry.

2. Materials and Methods

2.1. NIPAM gel fabrication

The gel was prepared inside a fume hood under normal atmospheric conditions according to the process described by Senden and De Deene [15, 16]. The NIPAM polymer gel used in the study was composed of 5% gelatin, 5% NIPAM (97% pure; Sigma-Aldrich), 3% N,N'-methylene bisacrylamide,



and 5 mM Tetrakis (hydroxymethyl) phosphonium chloride. After completing the gel preparation, the gel was poured into cylindrical acrylic phantoms with the following dimensions: 10 cm (diameter), 10 cm (height), and 3 mm (wall thickness). The gel phantom was wrapped in aluminum foil to prevent photopolymerization, and then cooled to 7 °C a water bath placed inside a refrigerator for 5 h until complete solidification was achieved. Two independent gel phantom batches were prepared for the replicated experiments.

2.2. Treatment planning system and irradiation

A simple field (4 cm × 4 cm) irradiation treatment plan was generated using the Eclipse planning system (Varian Corporation, Palo Alto, CA, USA). The gel phantom was fixed on a table with crossmarks for alignment. The gel phantom was irradiated using a Varian Clinac IX linear accelerator (Varian Corporation, Palo Alto, CA, USA). The treatment field was 4 cm × 4 cm square fields with gantries aligned at 270°. The prescribed dose was 5 Gy. The dose rate was 300 cGy (559 MU), the focal point setting was at the center of the gel phantom, the source surface distance was 96 cm, and the depth was 4 cm.

2.3. Dose readout tool and data analysis

In this study, a commercial 10X fast optical-CT scanner (OCTOPUS-10X, MGS Research, Inc., Madison, CT, USA) was used as the readout tool of the NIPAM polymer gel dosimeter. The special scanning system comprises collimating Fresnel lens and an oscillating mirror located at the focus of the Fresnel lens. One gel phantom scan only takes about 30 min. A single-beam laser (780 nm wavelength, 30 mW) was used to scan the gel phantom. The laser beams scan the gel that is mounted on a turntable inside the scanning tank, which is filled with a refractive-index matching liquid. The refractive index of NIPAM gel was measured using an ATAGO refractometer (model PAL-RI). Refractive index matching ensures that the gel-transmitted rays propagate in a straight direction. After scanning, the image reconstruction program “reconQexp.m” written in MATLAB (The MathWorks, Natick, MA, USA) was used to reconstruct the projection data using the filtered back-projection technique. The final data presentation of the reconstructed image and the dose calibration were performed using the image-processing program ImageJ (version 1.43) developed by the National Institute of Health. Quantitative evaluation of dose distributions was performed using gamma analysis [17, 18]. The measured NIPAM gel dose distributions were compared with the calculated treatment planning (TPS) dose distribution using 4% dose difference and 4 mm distance-to-agreement (DTA) comparison criteria.

3. Results and Discussion

Figure 1 shows the results of gel containers filled with un-irradiated NIPAM gel. Figure 1(a) indicates the reconstructed image of a transverse slice at 40 cm depth. Figure 1(b) indicates the line profiles at various depths (2.0, 3.0, 4.0, and 5.0 cm) along the line shown in Fig. 1(a). The gel uniformity can be evaluated using the uncertainty among these profiles at various depths [12]. The average uncertainties are 1.77% and 1.91% in the central 5.5 cm region for gel phantom batches 1 and 2, respectively. However, the maximum uncertainties are located at the edge of the same region, and are 3.72% and 3.13% for gel phantom batches 1 and 2, respectively. The spatial uniformity of NIPAM gel is found to be similar with BANG 3 polymer gel [12]. The large uncertainty at the edge of the central region of the gel may be caused by the scanner [12]. Due to the adoption of a smaller phantom diameter (10 cm), the refractive effect at the phantom wall is more serious. Thus, a larger phantom diameter should be adopted.

Figure 2 shows the results of irradiated gel phantom 48 h post-irradiation. Figure 2(a) indicates the reconstructed image of a transverse slice at 4.0 cm depth. Figure 2(b) indicates the line profiles of gel phantom batch 1 for different scanning results along the line shown in Fig. 2(a). The deviations of two scans for batches 1 and 2 at various depths are listed in Table 1. The maximum mean deviation is from 3.44% to 3.79% in the center 5.5 cm region, and the uniformities of the gel measured in different scans and different batches are found to be consistent in various depths.

Figure 3 compares the results of the measured NIPAM gel dose distributions and the TPS. The gamma pass rates are between 94% and 95% at 40 mm depth for the two gel phantom batches using 4% dose difference and 4 mm DTA criteria. The gamma map in Fig. 3 presents the rejected regions at the central region and edge of the 4 cm × 4 cm square field, where high-dose gradients are present. This erroneous phenomenon is probably a result of the edge enhancement of NIPAM gel, which

causes the disagreement at the high-dose-gradient region. However, another reason may be the repositioning error between the un-irradiated and irradiated gel scans, which needs further verification.

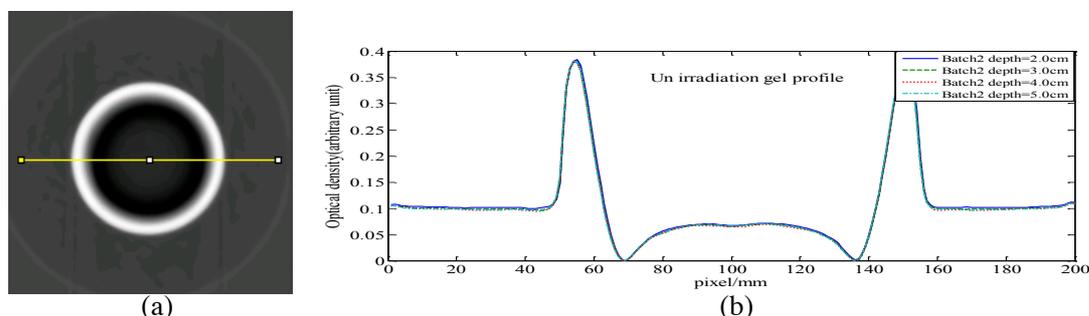


Figure 1. Scanning results of gel containers filled with un-irradiated NIPAM gel: (a) reconstructed image of a transverse slice (40 cm depth), (b) line profile at various depths along the line shown in (a).

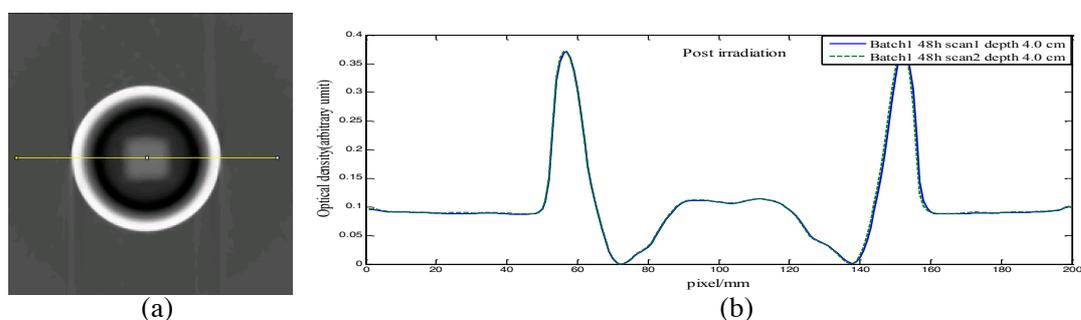


Figure 2. Scanning results of gel containers filled with irradiated NIPAM gel: (a) reconstructed image of a transverse slice (40 cm depth), (b) line profile at various depths along the line shown in (a).

Table 1. Measurement deviation of two scans at various depths for different batches of irradiated NIPAM polymer gel.

Batch No.	Batch 1		Batch 2	
Depth (cm)	3	4	3	4
Deviation	3.54%	3.44%	3.45%	3.79%

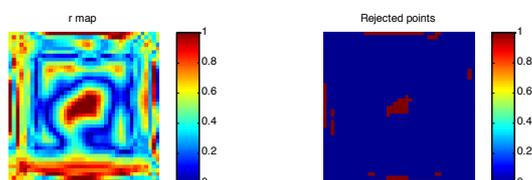


Figure 3. Representative 3D gamma comparison map of calculated treatment planning and the measured NIPAM gel dose using 4% dose difference and 4 mm distance-to-agreement criteria.

4. Conclusion

The present study investigated the reproducibility and spatial uniformity of a NIPAM polymer gel dosimeter. The spatial uniformity of NIPAM polymer gel was similar with the commercial BANG 3 polymer gel. Highly reproducible NIPAM polymer gel was obtained. The gamma index calculation showed that the gamma pass rates were between 94% and 95%. The prepared NIPAM polymer gel dosimeter has great potential in radiotherapy.

5. References

- [1] Baldock C *et al* 2010 *Phys. Med. Biol.* **55** R1-63
- [2] Trapp J V *et al* 2002 *Phys. Med. Biol.* **47** 4247-58
- [3] Lepage M *et al* 2001 *Phys. Med. Biol.* **46** 2827-39
- [4] Brindha S *et al* 2004 *Phys. Med. Biol.* **49** N353-61
- [5] Gustavsson H *et al* 2004 *Phys. Med. Biol.* **49** 227-41
- [6] Hill B *et al* 2005 *Br. J. Radiol.* **78** 623-30
- [7] Chang Y J *et al* 2011 *Nucl. Instrum. Methods Phys. Res. A* **652** 783-5
- [8] Salomons G J *et al* *Phys. Med. Biol.* **47** 1435-48
- [9] De Deene Y *et al* 2007 *Phys. Med. Biol.* **52** 2719-28
- [10] Rintoul L *et al* 2003 *Appl. Spectrosc.* **57** 51-7
- [11] Xu Y 2003 *Med. Phys.* **30** 2257-63
- [12] Xu Y 2004 *Med. Phys.* **31** 3024-30
- [13] Xu Y 2010 *Med. Phys.* **37** 861-8
- [14] Murry P and Baldock C 2000 *Australas. Phys. Eng. Sci. Med.* **23** 44-51
- [15] De Deene Y *et al* 2002 *Phys. Med. Biol.* **47** 3441-63
- [16] Senden R J 2006 *Phys. Med. Biol.* **51** 3301-14
- [17] Low D A 1998 *Med. Phys.* **25** 656-61
- [18] Low D A 2003 *Med. Phys.* **30** 2455-64