NIPAM polymer gel dosimetry for IMRT four-field box irradiation using optical-CT scanner

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Abstract. The study assessed the dosimetric characteristics of the N-isopropylacrylamide (NIPAM) polymer gel dosimeter. Experiments on the intra-dosimeter consistency and reproducibility of NIPAM polymer gels were performed. A cylindrical NIPAM gel phantom measuring 10 cm (diameter) by 10 cm (height) by 3 mm (thickness) was irradiated using the four-field box treatment with a field size of 3 cm \times 3 cm. A fast, optical computerized tomography scanner was used to scan the gel phantoms. The results showed that the dose profiles were consistent at various depths. The isodose lines agreed quantitatively with the calculated TPS dose and the measured NIPAM polymer gel dose within the 30 to 90 percentage isodose lines. In addition, the Gamma pass rates were determined to be 94.9\%, 95.2\%, and 95.7\% at depths of 40 mm, 45 mm, and 50 mm, respectively, using 5\% dose difference and 5 mm distance-to-agreement criteria. Using the same Gamma criteria, the Gamma pass rates were 95.1\%, 95.3\%, and 95.7\% for the three replicated. The results indicated that the NIPAM polymer gel dosimeter was stable and reliable. The dosimetric characteristics highlighted the potential of NIPAM polymer gel dosimeter in radiotherapy.

1. Introduction

The rapid development of complex radiotherapy technologies, such as intensity-modulated radiation therapy (IMRT), cyber knife, tomotherapy, proton therapy, and brachytherapy, has made dose verification highly important [1-5]. One-dimensional and two-dimensional dose detectors are deemed insufficient for dose measurement in 3D complex distributions [6]. Polymer gel dosimetry is one of the most promising candidates in three-dimensional dosimetry for radiation therapy. However, oxygen (O\textsubscript{2}) inhibition terminates the chemical polymerization reaction [7]. Thus, antioxidants must be added to the gel compositions for gel preparation in the laboratory [8-11]. Fong et al. developed a nontoxic...
MAGIC gel with less harmful gel monomers and compositions [8]. Senden et al. proposed the polymer gel, N-isopropylacrylamide (NIPAM) [11], which shows higher dose-response sensitivity and lower dose-rate dependence. In addition, Chang et al. revealed the long time temporal stability and high linearity of NIPAM polymer gel compositions [12]. In the present study, the NIPAM polymer gel recipe proposed by Chang et al. [12] was used in the IMRT four-field box irradiation to assess the internal uniformity and the reproducibility of dose response.

2. Materials and Methods

2.1. Gel preparation
The NIPAM polymer gel used in the study was composed of 5% gelatin, 5% NIPAM (97%, Sigma-Aldrich), 3% Bis (N,N'-methylene bisacrylamide), and 5 mM Tetrakis (hydroxymethyl) phosphonium chloride. The gel was formulated inside a fume hood under normal atmospheric conditions. Subsequently, the preparation process described by Senden and De Deene [8, 9] was performed. 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 photo-polymerization and then cooled to 7 °C in a refrigerator with water bath for 5 h until complete solidification was achieved. Three independent batches of gel phantoms manufactured at different lengths of time were prepared for the replicated experiments.

2.2. Treatment planning system and irradiation
A commissioned PROWESS treatment planning system was used to design the four-field box irradiation. The gel phantom was fixed using a vacuum bag with cross marks for alignment. The gel phantom was irradiated through IMRT (SIEMENS ONCOR Impression). The treatment field comprised four identical 3 cm × 3 cm square fields with gantries aligned at 0°, 90°, 180°, and 270°. The prescribed dose was 10 Gy at a beam-beam average dose of 2.5 Gy. The dose rate was 250 cGy, the focal point setting was at the center of the gel phantom, and the source surface distance (SSD) was 95 cm.

2.3. Scanning and data analysis
In this study, MGS OCTOPUS-10X Optical-CT scanner (MGS Research, Inc., Madison, CT, USA) was used as the read-out tool of the NIPAM polymer gel dosimeter. A single beam laser (780 nm wavelength, 30 mW) was used to scan the gel phantom, which was mounted on a turntable inside the scanning tank filled with a refractive-index matching liquid. Refractive index matching ensures that the rays transmitted by the gel 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 Java image-processing program ImageJ (version 1.43) developed by the National Institute of Health (NIH). Quantitative evaluation of dose distributions [13] was performed using gamma analysis [14, 15]. In this study, the measured NIPAM gel dose distributions were compared with the calculated treatment planning (TPS) dose distribution using 3% dose-difference and 5 mm distance-to-agreement (DTA) comparison criteria.

3. Results and Discussion
Figure 1 shows the line profiles of NIPAM polymer gel dosimeter at depths of 40 mm, 45 mm, and 50 mm for the post-irradiation time of 24 h. The maximum mean deviation is less than 3% in the center 4 cm region and the result indicates that intra-uniformity of gel is consistent in multiple slices.

Figure 2 shows the transverse view of the corresponding isodose lines at a depth of 40 mm. The calculated TPS dose (dashed line) and the measured NIPAM polymer gel dose (solid line) agree well
within the 30 to 90 percentage isodose lines. However, the dose difference along the edge of the square field is larger than that in other regions. This erroneous phenomenon is probably a result of edge enhancement. The consistent results can be observed from the Gamma map (figure 3). The rejected regions are presented at the edge of the square field where high dose gradient are present.

Table 1 shows that the Gamma pass rates are 94.9%, 95.2%, and 95.7% at depths of 40 mm, 45 mm, and 50 mm, respectively, using 5% dose difference and 5 mm DTA criteria. Utilizing the same Gamma criteria, the Gamma pass rates for the three replicated experiments are 95.1%, 95.3%, and 95.7% (Table 2). Based on these values, the NIPAM polymer gel dosimeter is deemed very stable and reliable.

Figure 1: Line profiles at depths of 40, 45, and 50 mm for post-irradiation time of 24 h

Figure 2: Isodose comparison between calculated TPS dose (dashed line) and measured NIPAM polymer gel dose (solid line)

Figure 3: Representative 3D gamma comparison map of TPS and the measured NIPAM gel dose using 5% dose difference and 5 mm distance-to-agreement criteria
Table 1. Gamma index at various depths of NIPAM polymer gel

| Depth (mm) | 40 | 45 | 50 |
|------------|----|----|----|
| Gamma criteria | 5%/5 mm | 5%/5 mm | 5%/5 mm |
| Pass rate | 94.9% | 95.2% | 95.7% |

Table 2. Gamma indices of three batches of NIPAM polymer gel

| Batch | 1 | 2 | 3 |
|-------|---|---|---|
| Gamma | 5%/5 mm | 5%/5 mm | 5%/5 mm |
| Pass rate | 95.1% | 95.3% | 95.7% |

4. Conclusion
This detailed investigation of NIPAM polymer gel dosimeter provided promising results. The NIPAM polymer gel dosimeter showed stable and reliable results from intra-dosimeter comparison and replicated experiments. Likewise, the isodose lines agreed well for the 30 to 90 percentage ranges in transverse view. The dosimetric characteristics indicated that the NIPAM polymer gel dosimeter has great potential in radiotherapy.

5. References
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