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Optical and NMR dose response of N-isopropylacrylamide normoxic polymer gel for radiation therapy dosimetry

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ABSTRACT

Background: Application of less toxic normoxic polymer gel of N-isopropyl acrylamide (NIPAM) for radiation therapy has been studied in recent years.
Aim: In the current study the optical and NMR properties of NIPAM were studied for radiation therapy dosimetry application.
Materials and methods: NIPAM normoxic polymer gel was prepared and irradiated by 9 MV photon beam of a medical linac. The optical absorbance was measured using a conventional laboratory spectrophotometer in different wavelengths ranging from 390 to 860 nm. R_2 measurements of NIPAM gels were performed using a 1.5 T scanner and R_2–dose curve was obtained.
Results: Our results showed R_2 dose sensitivity of $0.193 \pm 0.01\,s^{-1}\,Gy^{-1}$ for NIPAM gel. Both R_2 and optical absorbance showed a linear relationship with dose from 1.5 to 11 Gy for NIPAM gel dosimeter. Moreover, absorbance–dose response varied considerably with light wavelength and highest sensitivity was seen for the blue part of the spectrum.
Conclusion: Our results showed that both optical and NMR approaches have acceptable sensitivity and accuracy for dose determination with NIPAM gel. However, for optical reading of the gel, utilization of an optimum optical wavelength is recommended.

1. Background

Investigation on polymer gel dosimetry for radiation dosimetry has been the subject of a large number of studies in radiation dosimetry for two decades.[7,8,10,17,18,21] In spite of several exclusive advantages of this type of dosimetry, there have been also some factors to postpone its routine clinical application in many radiation therapy institutions.[20] Among the disadvantages, high toxicity of monomers used has been a considerable obstacle to overcome for many investigators.[3–5,18] In recent years a great amount of efforts has been made to facilitate their usage in clinic by finding new low toxic monomers as well as gel dosimeter fabrication in

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normal atmospheric conditions.[3,6,18] N-isopropyl acrylamide (NIPAM) polymer gel dosimeter was first studied by Senden et al. and its appropriate dosimetric properties for radiation therapy application were reported.[18] Dosimetric data acquisition by different methods, such as MRI, optical CT and X-ray CT were investigated separately by different groups.[1–3,18] In the study of Ghavami et al. the X-ray CT dose response of the NIPAM gel was investigated. The results showed that X-ray CT dose readout has potential for application in radiation therapy dosimetry, but further developments are required for its practical application in radiotherapy.[3]

Application of optical systems to extract dosimetric data from polymer gels has been the subject for research from ever since gel dosimetry was invented.[11,12,16] Using optical systems for polymer gel dose readout allows users to overcome dependency on magnetic resonance imaging systems in busy hospitals. Also, the long time and high price of R_2 measurements by MRI systems can be avoided using an affordable and easy to use optical system in a laboratory environment.[9,11–16,19,23] As far as we know, the optical dose sensitivity of NIPAM gel and its dependency on light wavelength have not been reported. So, it was the objective of the current study to address the unresolved issues in this regard. Additionally, in the current study the NIPAM polymer gel characteristics were studied by two data acquisition methods, including optical absorption measurements and magnetic resonance imaging and results were compared with previous studies.

2. Aim

The aim of the current study was to investigate the optical and magnetic resonance properties of NIPAM gel for application in radiotherapy dosimetry.

3. Material and methods

3.1. Gel preparation and irradiation

According to previous studies,[3,18] gel dosimeters contained gelatin (5 wt%), monomer (3 wt%), N,N′-methylene-bis-acrylamide crosslinker (3 wt%) and tetrakis (hydroxymethyl) phosphonium chloride antioxidant (10 mM). The polymer gel dosimeters were manufactured inside a fume hood, and under normal atmospheric conditions. The gel consists of NIPAM (Aldrich, 97%) and Bis acrylamide and Tetrakis hydroxymethyl phosphonium chloride (THPC) antioxidant were made using standardized procedures to maximize the reproducibility of gel preparation. At first step, gelatin (300 Bloom Type A) was allowed to swell in 80% of the de-ionized water for 10 min at room temperature, then the solution was heated up to 50 °C. While being stirred continuously, 3 wt% Bis was added to the solution at 50 °C, which took about 15 min, followed by the same amount of NIPAM monomer. Then, the gelatin–crosslinker mixture was cooled to approximately 37 °C. Finally, a solution of the antioxidant THPC was prepared with the remaining 20% of water, and added to the solution. The gels showed itself as a clear, transparent and slightly yellow liquid. The gel solutions were transferred into cylindrical vials with a diameter of 1 cm and a volume of 10 mm^3, and then closed with rubber caps. One vial was not irradiated for background reading and the other vials were irradiated with 9 MV photon beam of Neptun linear accelerator. The vials were placed in the holes within a polyethylene block with the dimension of 30 cm × 15 cm × 10 cm. The dose distribution and dose homogeneity around vials were evaluated using the Alfard treatment planning system. The vials were irradiated with 1.5, 3, 5, 7, 9, and 11 Gy. The irradiation setup is shown in Fig. 1.

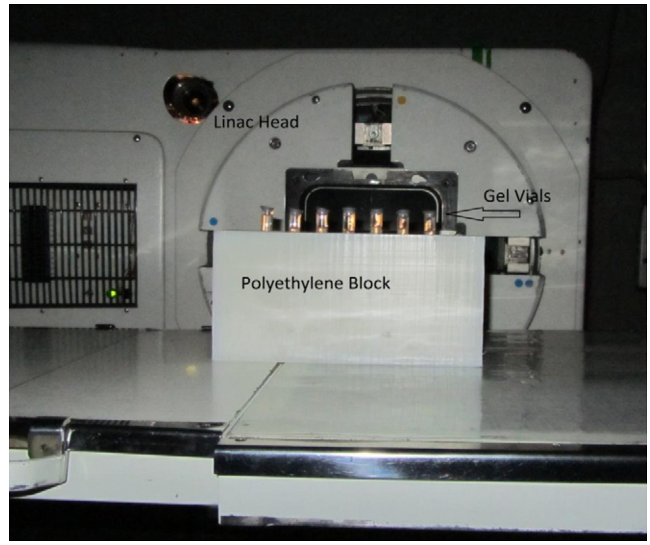

Fig. 1 – The experimental setup for gel irradiation. The white block shows the polyethylene block used for vials irradiation.

3.2. Optical absorbance of irradiated gels

A conventional laboratory spectrophotometer, Spectronic 20D (Milton Roy Company, Belgium) was utilized. A vial with distilled water was used for the zero absorbance calibration of the device. The optical absorbance of vials was measured at available wavelengths of visible light from 390 to 860 nm. For each vial, the absorbance measurements were repeated three times and the average value was used. Absorbance measurements were very reproducible with uncertainty less than 2% for all vials. For each set of measurement, the dose sensitivity of polymer gels in terms of absorbance per Gy was calculated.

3.3. Magnetic resonance imaging of irradiated gels

The irradiated vials were imaged using a 1.5 T magnetic resonance imager. To find R_2 of gels, 30 different protocols were used. Using Matlab software curve-fitting toolbox, the T_2 and therefore the R_2 values for all vials were obtained. For MR imaging, glass vials including non-irradiated and irradiated polymer gel samples were imaged using a 1.5 T clinical MRI scanner (Avento, Siemens, Erlangen, Germany). These samples were transferred to the MRI scanning room before imaging to equilibrate to room temperature (18 °C). All MR imaging was performed using a head coil. MRI