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**Original Article**

# Optical Characterization of NIPAM and PAGAT Polymer Gels for Radiation Dosimetry

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## Abstract

**Introduction**
The purpose of the current study was to determine optical sensitivity of N-isopropyl acrylamide NIPAM and polyacrylamide gelatin and tetrakis hydroxymethyl phosphoniun chloride (PAGAT) polymer gels for different wavelength of visible light spectrum applied in optical computed tomography method.

**Materials and Methods**
NIPAM and PAGAT polymer gels with conventional formulations used for polymer gel dosimetry in radiation therapy were prepared. Using a laboratory spectrophotometer, light absorbance against wavelength of light spectrum from 400 to 700 nm was measured. The optical absorbance-dose response curves were obtained for different wavelengths and the results were compared to find the wavelength where the highest sensitivity of polymer gels is occurred.

**Results**
The results showed light wavelength dependency for polymer gels optical absorbance-dose sensitivity. The highest sensitivity was seen in the blue part of visible light at wavelengths of 440 and 460 nm for PAGAT and NIPAM, respectively. Moreover, the sensitivity of NIPAM gel was higher than PAGAT for all studied wavelengths.

**Conclusion**
The sensitivity of both gels varied considerably with light wavelength and was higher in shorter wavelength of visible light. It is recommended to study optical absorbance-dose sensitivity of polymer gels for selecting the optimum light wavelength for optical measurements and optical computed tomography applications.

**Keywords:** Gel Dosimetry; NIPAM polymer; Optical Response; PAGAT polymer.

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# 1. Introduction

Polymer gel dosimetry of X-ray beams from medical linear accelerators has been an area of research for more than 30 years [1-6]. Unparalleled advantages of polymer gel dosimetry including three dimensional dose scoring property and soft tissue equivalency make it a demanding dosimetry approach for application in radiation therapy. However, the need for magnetic resonance imaging (MRI) for image acquisition and dose reading which is unavailable in most of laboratory environments as well as cost of imaging procedures have been the disadvantages of this dosimetry method. Thus, other approaches such as optical and X-ray computed tomography imaging have been used to substitute the expensive and time-consuming MRI method [7-10]. Optical measurement of gel absorbance has provided great results in terms of accuracy and reproducibility of readings and comparable results have been found for optical gel dosimetry method.

Nuclear magnetic resonance, X-ray attenuation, and optical absorbance of N-isopropyl acrylamide (NIPAM) have been studied by several studies [5, 6, 8, 10, 11]. However, recent advances in optical computed tomography units and their introduction into dosimetry apparatus market may arise some questions regarding their applications for different polymer gels [12-15]. In a recent study by Mesbahi et al. it was found that optical sensitivity of NIPAM gel is dependent on light wavelength used for measurement [16]. In short, it is important to know how these optical systems function for different types of polymers in terms of polymers' sensitivity for different wavelength of light spectrum. In the current study, we measured the optical absorbance of two polymers gels NIPAM and polyacrylamide gelatin and tetrakis hydroxymethyl phosphoniun chloride (PAGAT) in different wavelength of visible light spectrum.

# 2. Materials and Methods

### *2.1. Gel preparation*

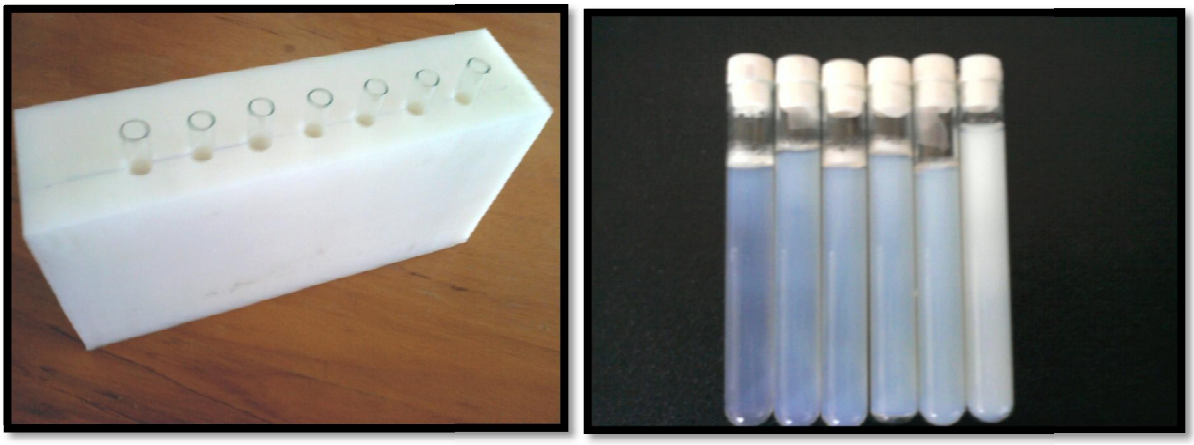
Polymer gel dosimeters (PAGAT, NIPAM) were prepared using the procedure described by Senden et al. [9] . The components of both gels are tabulated in Table 1. Gel dosimeters used in this study contained gelatin (5 wt%) (300 bloom, Pork skin, Sigma-Aldrich), monomers including N-isopropylacrylamide (NIPAM) or acrylamide (PAGAT) (both from Sigma-Aldrich, electrophoresis grade) (3 wt%), N,N-methylene-bis-acrylamide (3 wt%), and tetrakis (hydroxyl methyl) phosphonium chloride as an antioxidant (10 mM). The polymer gel dosimeters were prepared in a fume hood under normal atmospheric condition. The gels were made using standardized procedures to achieve highest reproducibility of gel preparation. To begin gel preparation, gelatin was allowed to swell in 80% of the deionized water at room temperature for 10 min, before heating to 50 ˚C. While stirring contionusly, the bis crosslinker was added at 50 ˚C, which took about 15 min before adding monomer. Then, the same amount of monomer (N-iso propylacrylamide as NIPAM monomer or acrylamide as PAGAT monomer) was dissolved and subsequently the gelatin-crosslinker mixture cooled to approximately 37 ˚C. The THPC solution was prepared with the remaining 20% of deionized water and stirred into the gel for 1 min (at a temperature of approximately 35 ˚C). The resulting gel was then poured into cylindrical glass vials with diameter of 1.2 cm and a volume 10 mm3, allowed to cool down at room temperature, and finally was sealed with rubber caps.

### *2.2. Gel irradiation*

Gels were irradiated for approximately 2 h post-manufacture with 9 MV photon beam of Neptun10PC linear accelerator (ZDAJ, Warsaw, Poland). The Irradiation time was based on our previous experiences on the fabrication of these gels [10,16]. For background reading, one vial was remained unirradiated and the others were irradiated with a 28×28 cm2 field size, at dose rate of 3 Gy/min and a source to isocenter distance of

100 cm. The vials were irradiated with a dose of 1, 3, 5, 7, 9, and 11 Gy for NIPAM and PAGAT gels. Higher doses were not used because the maximum optical absorbance of 2 was obtained at 9-11 Gy for both gels depending on used wavelength.

Gel irradiations were performed using a polyethylene block with the dimension of 30×15×10 cm3 containing 10 holes to fit gel vials (Figure 1). The vials were placed in the holes of polyethylene block before irradiation and the vials were located at the depth of 2 cm of beam entering surface. The dose homogeneity was verified using a conventional treatment planning system.



(A) (B)

Figure 1. (A) Polyethylene block and gel vials used in the current study. (B) Irradiated vials with different absorbed dose.

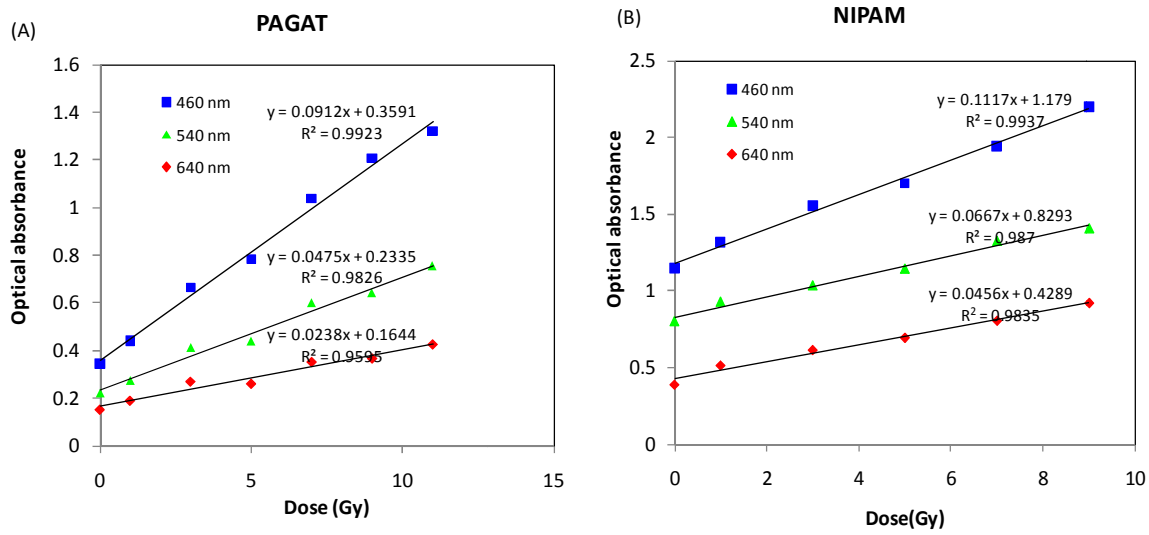



Figure 2. Optical absorbance of studied polymer gels versus absorbed dose measured in three wavelengths representatives of blue (460 nm), green (540 nm), and red (640nm) lights.

### *2.3. Optical absorbance of irradiated gels*

Optical absorbance of irradiated gels reading was done using a conventional laboratory spectrophotometer, Spectronic 20D (Milton Roy Company, Belgium). Spectrophotometer parameters used for absorbance measurement were the wavelengths of visible light from 400 to 700 nm with the step of 20 nm. Zero absorbance calibration of the device was done for each reading by a vial of distilled water. Optical absorbance measurements were repeated three times for each irradiated vial and the average values used for each vial.

We found very reproducible absorbance with uncertainty less than 3%. in Figure 3.

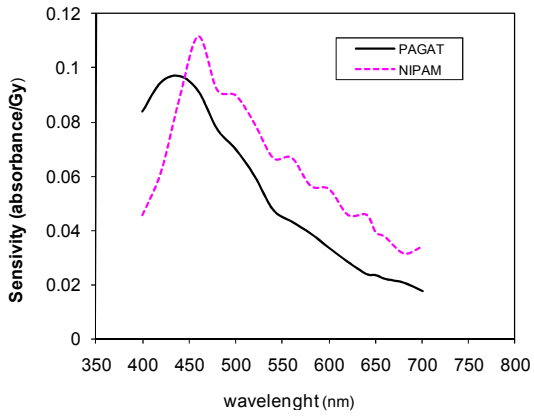



Figure 3. The sensitivity of PAGAT and NIPAM gels for different wavelengths of light spectrum used for optical measurements.

## 3. Results

The optical absorbance was plotted versus absorbed dose for each wavelength for both gels. The results are seen in Figure 2. Then, a linear line was fitted to all points using excel software (2007) and the slope of this fitting line was considered as the gel optical absorbance-dose sensitivity. The equation for each wavelength and its slopes were tabulated in Tables 2 and 3 for both polymer gels. To compare the sensitivity of NIPAM and PAGAT gels, their sensitivity for all studied wavelengths were plotted in Figure 3.

Figure 2 shows the optical absorbance-dose variations for both PAGAT and NIPAM gels measured by different wavelengths of light spectrum. As it is seen, the results were fitted suitably to a line with acceptable fitting R2 of 5% on average. The results indicate that the slope of optical absorbance-dose lines (sensitivity) are higher for blue light (450 nm) than others for both polymer gels. It means that the polymer gel sensitivity varies with the light wavelength used for reading out the optical absorbance after irradiation. In Figure 3, the sensitivity variation with wavelength for both gels as well as different light spectrum is plotted. As it is shown, the peak sensitivity happens at blue part (440-460 nm) for both NIPAM and PAGAT gels, while the lowest sensitivity is seen at the red part of light spectrum. However, the peak sensitivity for NIPAM occurs at slightly higher wavelength of 460 nm, where for PAGAT it is near the 440 nm. To have more detailed information on the optical measurements, the slopes of optical absorbance-dose line (sensitivity) have been written for both gels in different wavelengths in Tables 2 and 3. There is a peak for both gels at blue part of the spectrum, then after the peak, the sensitivity drops for higher wavelengths for both gels (Figure 3). On the other hand, comparing the peak sensitivity of NIPAM and PAGAT gels, it is seen that the maximum sensitivity of NIPAM gel is higher about 14% than maximum sensitivity of PAGAT gel (Table 2 and 3).

Table 2. The sensitivity of NIPAM polymer gel for different wavelengths of the visible light.

| Wavelength (nm) | Fitted equation | $R^2$ | Sensitivity (absorbance/Gy) |
|---|---|---|---|
| 400 | y = 0.0455x + 1.47 | 0.99 | 0.0455 |
| 420 | y = 0.0616x + 1.36 | 0.95 | 0.0616 |
| 440 | y = 0.0892x + 1.24 | 0.90 | 0.0892 |
| 460 | y =0.1117 x + 1.17 | 0.99 | 0.1117 |
| 480 | y = 0.0918x + 1.06 | 0.96 | 0.0918 |
| 500 | y = 0.0898x + 0.93 | 0.96 | 0.0898 |
| 520 | y = 0.0794x + 0.87 | 0.92 | 0.0794 |
| 540 | y = 0.0667x + 0.82 | 0.98 | 0.0667 |
| 560 | y = 0.0667x + 0.68 | 0.97 | 0.0667 |
| 580 | y = 0.0564x + 0.62 | 0.98 | 0.0564 |
| 600 | y = 0.0551x + 0.55 | 0.92 | 0.0551 |
| 620 | y = 0.0456x + 0.52 | 0.92 | 0.0456 |
| 640 | y = 0.0456x + 0.42 | 0.98 | 0.0456 |
| 650 | y = 0.0391x + 0.46 | 0.91 | 0.0391 |
| 660 | y = 0.0374x + 0.44 | 0.99 | 0.0374 |
| 680 | y = 0.0313x + 0.43 | 0.98 | 0.0313 |
| 700 | y = 0.0339x + 0.38 | 0.92 | 0.0339 |

Table 3. The sensitivity of PAGAT polymer gel for different wavelengths of the visible light.

| Wavelength (nm) | Fitted equation | $R^2$ | Sensitivity (absorbance/Gy) |
|---|---|---|---|
| 400 | y = 0.0838x + 0.59 | 0.93 | 0.0838 |
| 420 | y = 0.0946x + 0.49 | 0.96 | 0.0946 |
| 440 | y= 0.0968x + 0.41 | 0.97 | 0.0968 |
| 460 | y = 0.0912x + 0.35 | 0.99 | 0.0912 |
| 480 | y = 0.0773x + 0.32 | 0.97 | 0.0773 |
| 500 | y = 0.0698x + 0.27 | 0.97 | 0.0698 |
| 520 | y = 0.0600x + 0.24 | 0.97 | 0.0600 |
| 540 | y = 0.0475x + 0.23 | 0.98 | 0.0475 |
| 560 | y = 0.0431x + 0.20 | 0.96 | 0.0431 |
| 580 | y= 0.0388x + 0.18 | 0.94 | 0.0388 |
| 600 | y = 0.0334x + 0.17 | 0.94 | 0.0334 |
| 620 | y = 0.0283x + 0.17 | 0.98 | 0.0283 |
| 640 | y = 0.0238x + 0.16 | 0.95 | 0.0238 |
| 650 | y = 0.0234x + 0.14 | 0.92 | 0.0234 |
| 660 | y = 0.0220x + 0.15 | 0.94 | 0.0220 |
| 680 | y = 0.0206x + 0.13 | 0.93 | 0.0206 |
| 700 | y = 0.0175x + 0.13 | 0.91 | 0.0175 |

## 4. Discussion

As it can be seen from Figure 1-B, with increasing the absorbed dose from 1 to 11 Gy, the opacity of the polymer gel dosimeters increases and it allows us to evaluate the dose response by optical methods.

In Figure 2, it is seen that the response curves are linear up to 11 Gy for both gels and for all light wavelengths, which is in accordance with the results of Senden et al. in which the linear response of both PAGAT and NIPAM gels found to be up to 20 Gy [9]. Figure 2 shows that the optical absorbance of NIPAM gel at the zero absorbed dose is higher than PAGAT. However, the slope of absorbance-dose curves is higher for NIPAM in all parts of light

spectrum. In the preliminary study by Senden et al., the optical properties of several polymer gels including NIPAM and PAGAT were evaluated using a HeNe laser beam with wavelengths of 632.8 nm and the results showed that the optical sensitivity of NIPAM and PAGAT was very close together compared with their R2-dose response. However, the optical sensitivity of the NIPAM gel was slightly higher than PAGAT gel. Their study recommended a more thorough study of the light-attenuation properties of these polymer gels. In another study by DeJean et al. on both NIPAM and PAGAT gels applications for a cone beam optical CT unit, they analyzed the gel vials with 630 nm light beam and reported a linear response for two gels up to 5 Gy dose [17].

In Figure 3, it is evident that the sensitivity of NIPAM gel is higher than PAGAT gel for most of the used wavelengths. Moreover, in a similar pattern, the highest sensitivity occurs at blue part of light spectrum while the lowest sensitivity is seen at red region for both gels. In a quantitative way, it can be said that the peak sensitivities are seen at 460 and 440 nm for NIPAM and PAGAT, respectively. Our findings are consistent with the results of Mesbahi et al. [16]. They found that the NIPAM sensitivity varies with the wavelength of light and similar results were reported.

Polymer gel formulation and its optimization for optical measurements is a crucial issue for accurate and reproducible gel dosimetry. A recent study on optical scattering of polymer gels showed that type and amount of gelatin influence the light scattering artifact in imaging by optical CT [18]. In a similar way, our study showed that the optical absorbance of polymer gels depends strongly on wavelength and finding optimum wavelength for optical CT measurement can be considered as an important step in instrument design and fabrication.

## 5. Conclusion

The optical absorbance-dose response of two polymer gels, NIPAM and PAGAT were studied in different wavelengths of the visible light. The results showed that in optical measurement, the sensitivity of polymer gels are strongly dependent on the used light wavelengths and varies considerably with the monomer type used in polymer gel composition.

Our results showed that higher sensitivity of studied polymer gels happens in blue part of light spectrum (440-460 nm). Therefore, considering other affecting factors, these wavelengths of the visible light are preferred for light source selection in optical gel dosimetry systems. Additionally, the sensitivity of NIPAM gel was higher than PAGAT gels in all wavelengths. As a result, NIPAM showed better performance in terms of less toxicity nd optical characteristic compared with PAGAT.

For selecting the optimum light wavelength for optical measurements and optical computed tomography applications, more studies on optical absorbance-dose response of polymer gels are recommended.

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