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EFFECT OF PHOTON ENERGY ON THE RADIATION SENSITIVITY OF HEMA POLYMER GEL DOSIMETER BASED ON NEAR INFRARED EVALUATION

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ABSTRACT

This study investigates the photon energy dependence of HEMA polymer gel dosimeters (PGDs) with maltose additive, evaluated using near-infrared (IR) spectrophotometry. Two batches of PGDs with varying maltose concentrations (0–520 mM) were irradiated using 6 MV and 10 MV photon beams. Absorbance-dose response curves were plotted, and sensitivities were compared using regression analysis and ANOVA. Results indicated a significant difference in sensitivity between the two photon energies ($p < 0.05$), suggesting photon energy dependence in the evaluated HEMA PGDs. These findings emphasize the need for energy-specific calibration when using HEMA PGDs in clinical applications.

Keywords: HEMA Polymer Gel Dosimeter, Energy Independence, Sensitivity of Polymer Gel Dosimeter, Maltose Additive

INTRODUCTION

Photon source' energy independence is a feature that enhances the efficiency of polymer gel dosimeters (PGDs), for effective therapy planning system. There should not be a significant variation between the sensitivities or dose responses of any two sets of PGDs irradiated with different photons' energy (De Deene, 2022).

Previously, the photon and electrons' energy dependence of BANG was assessed by Farajollahi et al. (1999). The results demonstrated the photon and electron's energy independence of the PGD (Farajollahi et al., 1999). Methacrylic acid-based gel dosimeter (nMAG) and Acrylamide-based gel dosimeters (PAG and nPAG) were evaluated by Deene et al., 2006, using two photon energies (6 and 25 MV). The results reveal no variation in the dose response of both nPAG and PAG PGDs due difference in photon energy, but a small change was found with increment of the photon energy in the nMAG PGD (Deene et al., 2006). Sathiyaraj and Samuel (2018) reported that the photon energy dependence of MAGAT PGD in 6 MV and 10 MV photon energies was insignificant (Sathiyaraj & Samuel, 2018). Also, Sellakumar and Samuel (2010) reported insignificant difference due to photon's energy in PAGAT PGDs, using 1.25 MV, 6 MV, and 15 MV photon energies (Sellakumar & Samuel, 2010). Farajollahi et al. (2014) reported the photon energy independence of NIPAM PGDs in two photon energies (1.25 MeV and 9 MV) (Farajollahi et al., 2014).

However, not all PGDs are photon's energy independent. The effect of photon energy alongside the dose rate on the sensitivity of U-NIPAM, based on MRI R_2-dose response evaluation, was assessed by Mohammad et al., (2020). The U-NIPAN dosimeter was irradiated to 1-7 Gy, in step of 1 Gy interval, using 6 MV and 15 MV photon energies, and was found to be photon's energy dependent. Additionally, the photon's energy dependence of the R2-dose sensitivity of U-NIPAN can vary over time, post irradiation; contrary to R2-dose sensitivity dependence of the PGD which remains unchanged post irradiation time (Mohammad et al., 2020).

As not all PGDs possess photon's energy independence (Rabaeh et al., 2024), and photon's energy independence of some PGDs, including HEMA PGDs were not documented in literature (Muhammad et al., 2025), it is essential to examine such. The aim of this work is thus, to evaluate the photon's energy independence of 2-hydroxyethyl methacrylate (HEMA) PGDs with maltose additive, named here as HEMAM (HEMA + Maltose) using IR evaluation technique.

MATERIALS AND METHODS

Two batches of PGDs, each contains four sets of PGDs with different maltose concentrations (0 mM, 80 mM, 240 mM, and 520 mM) were prepared as described in (Alhassan et al., 2025). Each set was divided into 6 samples, inside cuvettes of size 4.5 mL, and were irradiated to doses 2, 4, 6, 8, and 10 Gy, while one sample was left as a reference sample. One batch was irradiated with 6 MV photon energy and the other using 10 MV photon energy. The PGDs were scanned using ultraviolet-visible-infrared (UV-Vis-IR) scanner. A graph of absorbance (Abs)-dose response curve was plotted for each sample. The sensitivity of the two sets was determined from Abs-dose curves, and comparisons were made between them, including their R^2 values, and ANOVA test was carried out to assess their difference.

RESULTS AND DISCUSSION

The Abs-dose response curves of the two sets are presented in Figure 1:

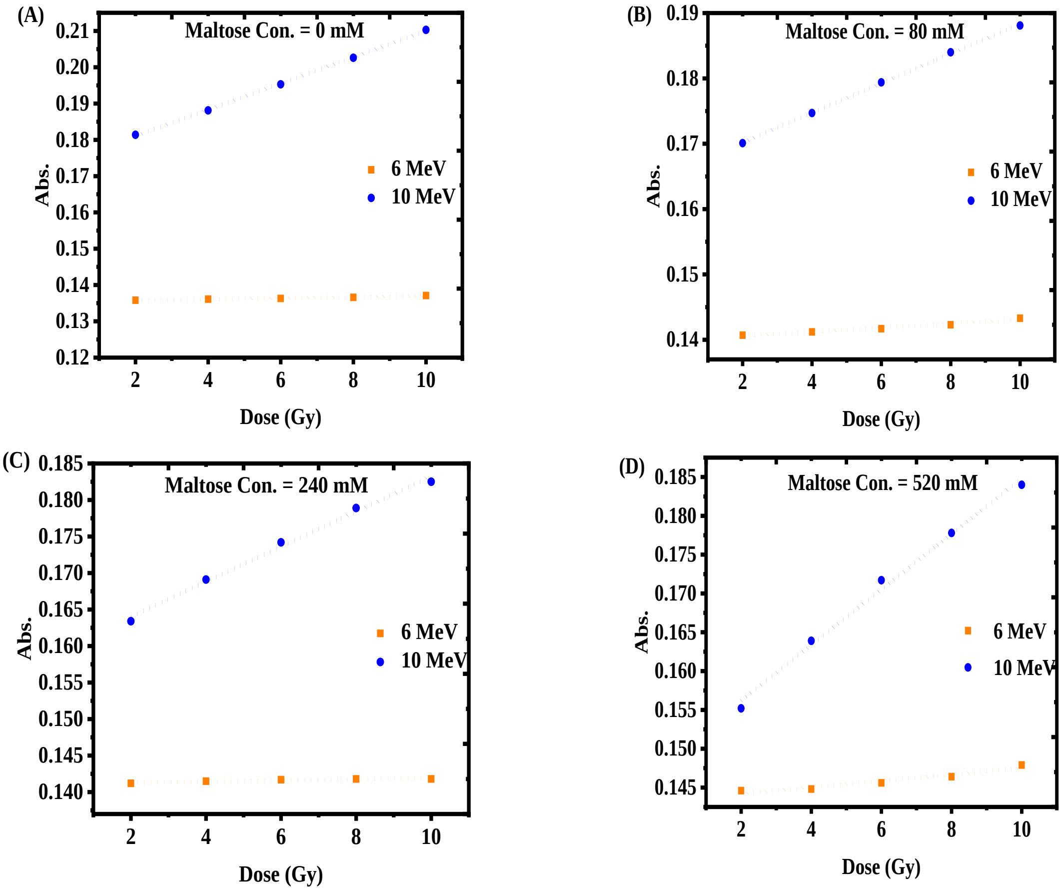

Figure 1: The Abs.-dose response of HEMAM PGDs with (A) Maltose concentration 0 mM, (B) Maltose concentration 80 mM, (C) Maltose concentration 240 mM, and (D) Maltose concentration 520 mM, each irradiated to doses within 2 – 10 Gy

Figure 1 presents the Abs.-dose response of HEMAM PGDs. The change in absorbance with increasing absorbed dose within 2– 0 Gy shows a linear relationship in both sets of the PGDs. The fitting parameter (R^2) values for the two sets with equal maltose concentration are presented in Table 1.

Table 1: Comparison between the fitting parameter R^2 of the Abs.-dose graphs for 6 MV and 10 MV photon energies

Variable	Maltose Conc. (mM)	Photons' Beam Energy	
		6 MV	10 MV
	0	0.9727	0.9994
R^2	80	0.9747	0.9994
	240	0.8654	0.9933
	520	0.9298	0.9934
Average R^2	-	0.9357	0.9964

The sensitivity values of the PGDs, obtained from the slope of the Abs.-dose response curves of the two sets of PGDs, are compared in Figure 2.

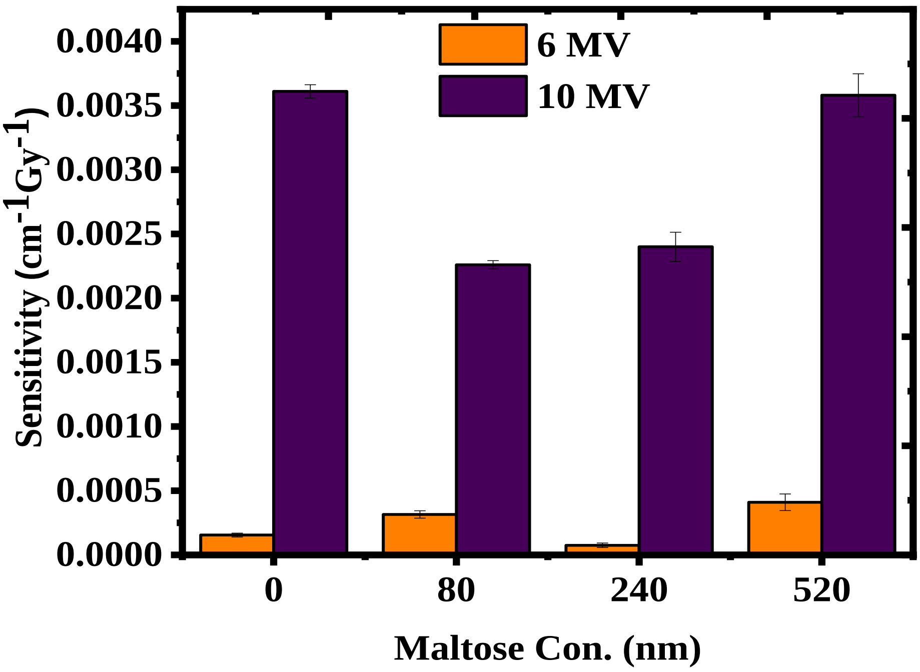

Figure 2: Sensitivity values at four maltose concentrations in PGDs irradiated using 6 MV LINAC compared to PGDs irradiated using 10 MV LINAC

Figure 2 reveals that, unless for PGDs without maltose (0 mM), the sensitivity values of PGDs irradiated using 10 MV LINAC is lower at lower maltose concentration, and increase with an increase in maltose concentration up to 520 mM, whereas, for samples irradiated using 6 MV LINAC, unless for PGD with maltose concentration 240 mM, the sensitivity is lower at lower maltose concentration, and increases with increasing maltose concentrations up to 520 mM.

To test if the difference between the sensitivities due to the two types of photons' energy is significant or otherwise, a single-factor analysis of variance (ANOVA) test was conducted. We hypothesize with a 95% confidence level ($p = 0.05$), with the null hypothesis stating that there is no significant difference in the sensitivities of the two sets of PGDs, while the alternate hypothesis states that there is a significant difference in the sensitivities of the two sets of PGDs. The result of the ANOVA test is presented in Table 2.

Table 2: ANOVA Test Result, comparing the sensitivities of PGDs irradiated using 6 MV and 10 MV photon energies

Source of Variation	SS	Df	MS	F	p-value	F crit
Between Groups	1.48×10^{-5}	1	1.48×10^{-5}	53.0091	0.0003	5.9874
Within Groups	1.68×10^{-6}	6	2.8×10^{-7}			
Total	1.65×10^{-5}	7				

The results presented in Table 3 indicate that the p-value is 0.0003, rounded to 4 d.p. Since $p < 0.05$, we have to reject the null hypothesis. Also, the calculated F-value (53.0091), rounded to 4 decimal places (d.p) is higher than the critical F-value (5.9874), we, therefore, accept the alternate hypothesis, and conclude that there is a significant difference between the sensitivities of the dosimeters irradiated using 6 MV and those irradiated using 10 MV photon's energies.

Another indicator of the difference between the two photons' energies is the difference between their variances. The variance in the sensitivities of 6 MV photon energy is 2.3×10^{-8}, while that in 10 MV photon energy is 5.37×10^{-7}. Therefore, photon energy might have affected the performance of the PGDs under study. This observation is consistent with the observed significant difference between the sensitivity of U-NIPAN PGD, due to difference in photon energy (6 MV and 15 MV), irradiated within 0–7 Gy dose range, taking ($P < 0.05$) (Mohammad et al., 2020).

The reason behind the significant variation in the sensitivity of the HEMAM PGDs irradiated using two different photon energies 6 MV and 10 MV might be attributed to the relative fraction of interaction processes in the PGDs, which is a function of incident radiation energy; as different photon energies produce different water radiolytic products, thus, difference in the dose response of PGDs over photon energy is expected (Deene, 2004). Additionally, the two sets of PGDs being prepared separately, might have differed significantly due to extra-batch effect. The two factors may collectively contribute to this significant difference between the dose responses as well as the radiation sensitivities.

CONCLUSION

This study examined the response of HEMA PGDs with varying maltose concentrations to two photon energies (6 MV and 10 MV). The results showed a statistically significant difference in dose sensitivity between the two energy levels, indicating photon energy dependence. This dependence may be due to energy-dependent variations in radiolytic yield and potential inter-batch variability. Further investigation involving broader energy ranges, including those used in diagnostic imaging, is recommended to fully characterize the photon energy response of HEMA PGDs.

REFERENCES

Alhassan, M., Rahman, A. A., Mustafa, I. S., Zahri, M., Aziz, A., Kassim, M. Z., Abdullah, M. S., Ibrahim, H. A., & Bala,

K. A. (2025). A Novel Approach to Evaluating HEMA Polymer Gel Dosimeters Using Molecular Vibrational Features. *Pertanika Journal of Science and Technology Sci. & Technol.*, *33*(2), 1049–1068.

De Deene, Y. (2022). Radiation Dosimetry by Use of Radiosensitive Hydrogels and Polymers: Mechanisms, State-of-the-Art and Perspective from 3D to 4D. *Gels*, *8*(9), 599.

Deene, Y. De. (2004). Essential characteristics of polymer gel dosimeters. *Journal of Physics: Conference Series*, *3*, 34–57.

Deene, Y. De, Vergote, K., Claeys, C., & Wagter, C. De. (2006). The fundamental radiation properties of normoxic polymer gel dosimeters: a comparison between a methacrylic acid based gel and acrylamide based gels. *Physics in Medicine and Biology*, *51*(3), 653–673.

Farajollahi, A., Bonnett, D., Ratcliffe, A., Aukett, R., & Mills, J. (1999). An investigation into the use of polymer gel dosimetry in low dose rate brachytherapy. *Br. J. Radiol.*, *72*, 1085–1092.

Farajollahi, A., Pak, F., Horsfield, M., & Myabi, Z. (2014). The basic radiation properties of the N-isopropylacrylamide based polymer gel dosimeter. *Int. J. Radiat. Res.*, *12*, 347–354.

Mohammad, S., Abtahi, M., Anaraki, V., Farhood, B., & Rabi, S. (2020). Assessment of photon energy and dose rate dependence of U-NIPAM polymer gel dosimeter. *Radiation Physics and Chemistry*, *172*(August 2019), 108784.

Muhammad, A., Azhar, A. R., Shahrim, I., Aziz, A., & Zahri, M. (2025). Impact of Maltose Additive on Improving the Radiation Sensitivity of HEMA Polymer Gel Dosimeter for Radiotherapy. *Engineering Highway*, *15*, 79–87.

Rabaeh, K. A., Bani Issa, A. S., Ababneh, A. M., & Eyadeh, M. M. (2024). Enhancement the dosimetric properties of N-(3-methoxypropyl) acrylamide polymer gel dosimeter for cancer treatment. *Radiation Physics and Chemistry*, *216*(August 2023), 111441.

Sathiyaraj, P., & Samuel, J. J. (2018). Dose rate and energy dependence study of methacrylic acid gelatin tetrakis (hydroxymethyl) phosphonium chloride gel with flattened and unflattened photon beams. *J. Canc. Res. Therapeut*, *14*, 287–291.

Sellakumar, P., & Samuel, E. J. J. (2010). Study on energy dependence of PAGAT polymer gel dosimeter evaluated using X-ray CT. *Radiat. Meas.*, *45*, 92–97.