

Impact of Baseline Correction and the Reference Sample Type in UV-Vis Spectrometry on Maltose Optimization in HEMA Polymer Gel Dosimeters

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ABSTRACT

This study aims to investigate the influence of baseline correction methods and reference sample types, on the optical evaluation of 2-Hydroxyethyl Methacrylate (HEMA) polymer gel dosimeters (PGDs) doped with maltose, for optimization purposes. The HEMA PGDs were evaluated using Ultraviolet-Visible (UV-Vis) spectrometry, across 200-800 nm wavelength range. The analysis was carried out at 400 nm. Three baseline correction approaches were employed: Using (i) deionized water (RW), (ii) an un-irradiated sample in the reference holder (RS), and (iii) un-irradiated samples in both reference and sample holders (RSS). The results obtained demonstrate that the choice of baseline correction method and reference sample type influences the radiation sensitivity and dose-response behavior of HEMA-based polymer gel dosimeters (PGDs). Among the three baseline correction approaches tested, the RW method yielded the highest radiation sensitivity. Additionally, the optimal maltose concentration for maximizing PGD sensitivity varied with the baseline correction method, with less maltose needed to attain the highest sensitivity when RW is employed for the PGDs evaluation using UV-Vis. Future work may focus on extending these evaluations to different PGD formulations and on using additives other than maltose.

Keywords:

HEMA, Maltose,
Optical Evaluation,
Optimization,
Polymer Gel
Dosimeter,
UV-Vis.

INTRODUCTION

The most commonly used optical technique for evaluating irradiated polymer gel dosimeter (PGD) is Ultraviolet-Visible Spectrometry (UV-Vis). The UV-Vis spectrometer contains a light source with wavelengths covering ultraviolet (UV) and visible (Vis) light ranges. The UV-Vis instrument consists of a single or double light source, a detector, and an integrated electronic data processing system (Al-jarrah et al., 2016).

When light passes through a sample, its intensity changes. The difference between the incident light and the transmitted light represents the amount of light absorbed by the sample at each wavelength within the selected range (Caro & Claudia, 2015; Jaszczak et al., 2021). The intensity of transmitted light from the reference sample or its absorbance spectrum is subtracted from that of the scanned sample. This produces an absorption or transmittance spectrum, and reflects the radiation-induced changes at each wavelength. The spectrum typically includes a peak absorbance (A_p) at a specific wavelength, labeled as the wavelength of maximum absorbance (λ_{max}) (Al-jarrah et al., 2016; Chacón et al., 2018), which is characteristic of the sample.

Various options of baseline correction and choices of reference sample have been reported in literature. For example, while most authors used a single reference sample for baseline correction and the same sample as reference sample, Al-Jarrah et al. and Samuel et al. used two un-irradiated samples in the two samples' holders for the baseline correction (Al-jarrah et al., 2016; Samuel et al., 2015). And for reference sample, Mesbahi et al. used distilled water as a reference sample to evaluate NIPAM gel dosimeter (Mesbahi et al., 2012), Magugliani et al. and Samuel et al. used un-irradiated sample to evaluate PAGAT and PAGTEG gel dosimeters respectively (Magugliani et al., 2018; Samuel et al., 2015), and Lotfy et al. used sample which do not contain antioxidant, to evaluate NIBMAGAT gel dosimeter (Lotfy et al., 2017). Previously UV-Vis has been used to evaluate 2-Hydroxyethyl Methacrylate (HEMA) PGD containing maltose additive in UV region. In the study, three approaches to baseline correction and reference sample type were compared, specifically, (i) using deionized water in the reference holder (RW approach), (ii) using an un-irradiated sample in the reference holder (RS

approach), and (iii) using un-irradiated samples in both reference and sample holders (RSS approach). The study showed that RW approach yielded the highest sensitivity (Muhammad et al., 2025). However, in other studies by Ishak et al., (2015) and Mesbahi et al., (2012) the wavelength at which change in absorbance (ΔA) is recorded to evaluate PGDs was reported to affect their sensitivity (Ishak et al., 2015; Mesbahi et al., 2012). Consequently, a PGD evaluated at different wavelengths is expected to display different radiation sensitivities and efficiencies. This motivates the authors here to evaluate HEMA PGDs with maltose additive in the Vis region, in order to determine whether results remain consistent across the two spectral regions or not, and to identify the optimal approach.

The aim of this work is to assess the impact of the type of baseline correction method, and the reference sample type during UV-Vis evaluation of PGDs in Vis region, in order to optimize the maltose concentration in HEMA PGD. The significance of this study lies in exploration of the optimum maltose concentration in HEMA PGDs, and in identifying the most suitable baseline correction approach for UV-Vis spectrometric evaluation of HEMA PGDs. This will contribute to enhancing the performance of PGD in radiation dosimetry. The materials and methods of the study are described in Section 2.

MATERIALS AND METHODS

HEMA PGDs Preparation

The compositions of the HEMA PGD samples in this study are similar to those used in previous work (Muhammad et al., 2025), which are: 6.0% Gelatin (Type B, gel strength 225 g bloom), 2.7% HEMA, 89.0% deionized water, 2.0% N,N'-Methylene-Bis- Acrylamide (Bis), 0.3% Tetrakis (Hydroxymethyl) phosphonium chloride (THPC), and maltose of varying concentrations within 0- 520 mM.

The HEMA PGDs were prepared under normal atmospheric condition, following a procedure similar to one used previously (Muhammad et al., 2025). Firstly, Bis was dissolved in hot water, stirred using magnetic stirrer, followed by the addition of gelatin, maltose, HEMA, and THPC in that order. After all components were added, the mixture was stirred at room temperature to ensure uniformity. The resulting gel solution was then poured into cuvettes with dimensions of 1 cm × 1 cm × 4.5 cm. The cuvettes were then covered with parafilm and stored in a refrigerator at a controlled temperature of 4-6°C for gelation.

HEMA PGDIrradiation

Irradiation was performed after equilibrating the samples' temperature in air with the surrounding temperature (22 ± 0.5 °C) for at least 2 hours, as described previously (Alhassan et al., 2025). The samples were irradiated using 6 MeV photon energy, to doses 0-30 Gy, with average

dose rate of $540 \text{ Gy} \cdot \text{min}^{-1}$, delivered in a single fraction per exposure.

HEMA PGDDose Evaluation

The irradiated samples were scanned using a UV-Vis spectrometer, employing three different baseline correction approaches, and type of reference sample: (i) using deionized water in the reference holder for both baseline correction and as reference sample (labelled here as RW), (ii) using an un-irradiated sample in the reference holder and as reference sample (labelled here as RS), and (iii) using an un-irradiated sample in both the reference and sample holders, and using one un-irradiated sample as the reference (labelled here as RSS) (Al-jarrah et al., 2016; Samuel et al., 2015). The various approaches for the baseline correction are illustrated in Figure 1.

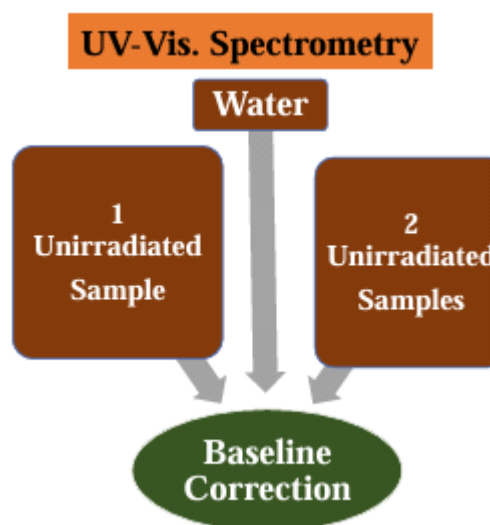


Figure 1 Various approaches to baseline correction for PGDs evaluation using UV-Vis spectrometry.

The PGDs were then scanned using either deionized water (Mesbahi et al., 2012) or an un-irradiated sample as the reference (Magugliani et al., 2018; Samuel et al., 2015). HEMA PGDs scanning was conducted across the wavelength range of 200 nm to 800 nm. ΔA was recorded at 400 nm. Absorbance-dose response curves were plotted and fitted to sigmoidal dose response curves. The impact of maltose as an additive on improving the radiation dose sensitivity of HEMA PGDs was evaluated based on the three baseline corrections approaches.

The radiation sensitivity of PGDs is defined as the slope of the linear region of the dose-response curve (Farhood et al., 2019), and was calculated for HEMA PGDs using Equation 1.

$$\text{Slope (Sensitivity)} = \frac{\Delta A}{\Delta D} \quad (1)$$

Where, ΔD is the change in dose.

RESULTS AND DISCUSSION

Dose-Response Curves

PGDs undergo polymerization upon irradiation, resulting in physical and chemical changes. The optical changes enable the evaluation of PGDs using UV-Vis spectrometer. The dose-response curves based on the three baseline correction approaches, with Absorbance taken at $\lambda_{\max} = 400$ nm are presented in Figure 2.

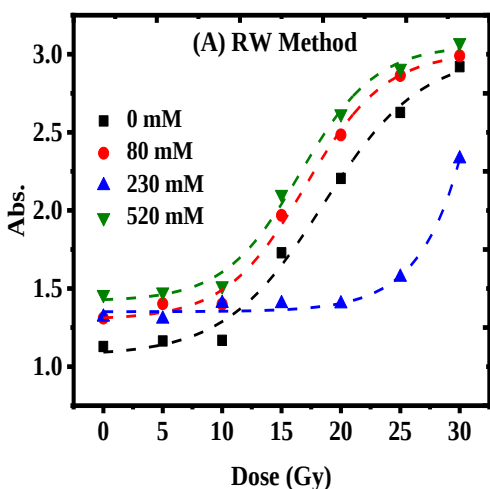


Figure 2a. HEMA PGDs using RW approach

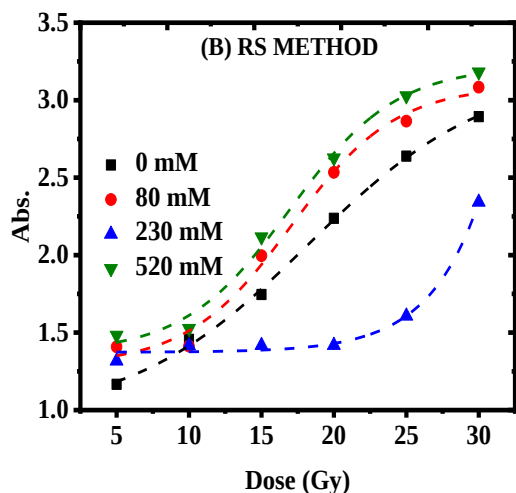


Figure 2b. HEMA PGDs using RS approach

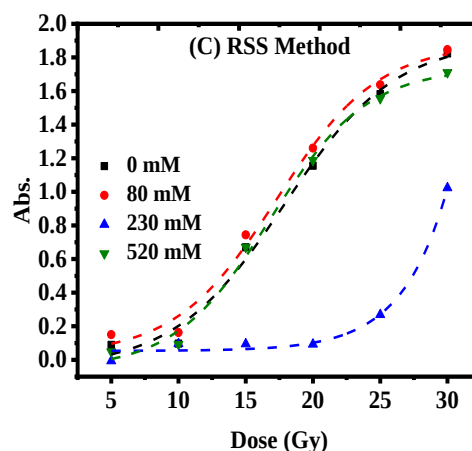


Figure 2c. HEMA PGDs using RSS approach

Figure 2a, 2b & 2c: Dose-Response Curves for HEMA PGDs with varying maltose concentrations. (A) Using RW approach, (B) Using RS approach, (C) Using RSS approach, respectively.

Figure 2a, 2b & 2c show an increase in absorbance with increasing absorbed dose. The sensitivity of the HEMA PGDs at the steepest points of the curves was determined for each of the RW, RS, and RSS approaches (Masithoh et al., 2023; Zapata et al., 2021). Figure 2a, 2b & 2c also show that the dose-response curves are non-linear. The curves show a gentle gradient at low doses, followed by a linear region, and eventually reach a saturation point where the curve flattens. These curves fit well to sigmoidal dose-response curves, with adjusted R^2 values ranging from 0.77 to 0.99.

Radiation Sensitivity

Radiation sensitivity is a key characteristic of PGDs. It reflects their ability to respond to small changes in absorbed doses. A higher sensitivity indicates a greater response per unit dose (De Deene, 2022; Farhood et al., 2019; Marrale & d'Errico, 2021).

The sensitivity of HEMA PGDs doped with maltose at various concentrations evaluated using the RW, RS, and RSS approaches, is plotted and illustrated in Figure 3.

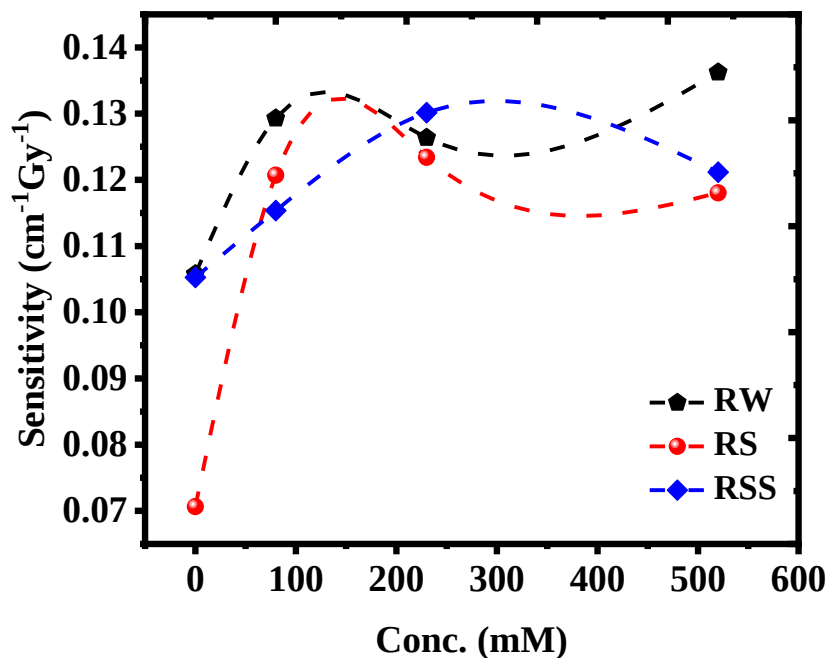


Figure 3. Variation of sensitivity with maltose concentration using different baseline correction approaches.

Figure 3 shows that radiation sensitivity increases with increasing maltose concentration. The RW approach yields highest sensitivity ($0.134 \text{ cm}^{-1}\text{Gy}^{-1}$), while RS and RSS both exhibit slightly lower maximum sensitivities ($0.133 \text{ cm}^{-1}\text{Gy}^{-1}$). These sensitivity values were calculated based on the steepest slope along the dose-response curve, using Hill's equation. This metric is useful for comparing PGDs and prioritizing their evaluation approach. These results highlight that the highest attainable sensitivity of HEMA PGDs, based on UV-Vis readout, is influenced by the amount of the maltose used, and by the baseline correction approach. Similar observation was reported when maltose-doped HEMA PGD was evaluated in UV region, where RW also yielded highest radiation sensitivity among the three approaches, although the optimum maltose concentration differs (Muhammad et al., 2025).

Also, the improvement in radiation sensitivity of HEMA PGDs through the addition of maltose, which is a saccharide, is consistent with similar enhancements observed when other saccharides, such as sucrose and glucose, were added to PAGAT (Berndt et al., 2015). Also a significant improvement in radiation sensitivity was achieved by adding sucrose to nMAG (Yoshioka et al., 2010). Both maltose and sucrose are disaccharides, whereas glucose is a monosaccharide.

The maltose concentrations at which the HEMA PGDs attain their maximum sensitivities are approximately 130 mM, 145 mM, and 300 mM for the RW, RS, and RSS approaches, respectively. These findings also demonstrate

the impact of baseline correction approach and the type of reference sample used during UV-Vis spectrometry on the optimum concentration of the maltose additive, and further show that less maltose is needed to attain the highest possible sensitivity when RW approach was employed during the evaluation of HEMA PGDs in UV region, using UV-Vis spectrometer. These results are not only hinting the optimization of maltose, but also hinting how to cut the cost of production of maltose-doped HEMA PGDs, since less maltose is needed to maximize the sensitivity of the dosimeters when RW approach was selected during the dose evaluation, thus, the study has an economic significance.

On the other hand, the variation in sensitivity due to different baseline correction approaches can be attributed to differences in the amount of absorption effect subtracted from the reference sample: In the RW approach, only the effect of water is subtracted from the sample holder, resulting in a higher resultant absorbance in RW. In contrast, the RS and RSS approaches account for the absorption effects of gelatin, residual monomers (HEMA and BIS), and maltose present in the un-irradiated HEMA PGD, which serves as the reference sample. These effects are subtracted from the sample holder to obtain the resultant absorbance spectra of the scanned samples (Al-jarrah et al., 2016). The effects of water and the cuvette material, being present in both holders, are canceled out in all the three approaches.

The difference between RS and RSS lies in the amount

of the effect zeroed in the sample holder prior to scanning. In RS, the effect of air is zeroed as noise, whereas in RSS, the effects of all the components in the un-irradiated PGD, are zeroed as noise. This distinction results in the lowest resultant absorbance obtained in RSS, followed by RS, and the highest obtained in RW. Consequently, their sensitivities follow the same order: highest in RW, followed by RS, and lowest in RSS.

CONCLUSION

This study demonstrates that the choice of baseline correction method and reference sample type evidently influences the radiation sensitivity and dose-response behavior of HEMA-based PGDs, evaluated using UV-Vis spectrometry. Among the three baseline correction approaches tested in this study: Using (i) deionized water in the reference holder (RW approach), (ii) an un-irradiated sample in the reference holder (RS approach), and (iii) un-irradiated samples in both reference and sample holders (RSS approach), the RW method yielded the highest sensitivity. Additionally, the optimal maltose concentration for maximizing PGD sensitivity varied with the baseline correction method, with least amount needed when RW approach is employed. These findings highlight the importance of standardizing optical readout techniques and emphasize the role of additive concentration in optimizing PGD performance for radiation dosimetry. Future work may focus on extending these evaluations to different PGD formulations other than HEMA-based PGDs, and on using additives other than maltose.

Declaration of Interest

The authors declare that there is no any conflict of interest regarding the publication of this work.

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