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Temporal Variation of the Polymerization in X-Ray- and Proton-Irradiated Radiochromic Films

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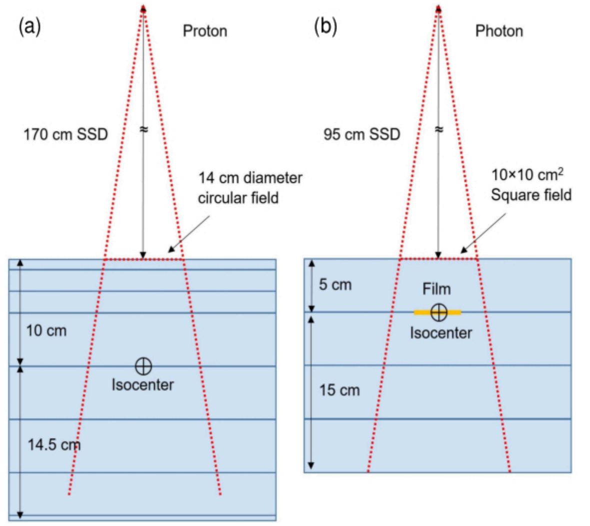
INTRODUCTION

Radiochromic films are an attractive choice for radiation therapy dosimetry owing to high spatial resolution and tissue equivalent dosimetric properties. The purpose of this study was to investigate the development of the response of the EBT-3 and XD radiochromic films over the course of first 120 hours after irradiation by measuring both the optical density of the films.

METHOD

- Samples from EBT3 and EBT-XD films (Ashland Inc., Bridgewater, NJ) from two different batches were cut to 5 x 5 cm^2 size.
- Photon irradiation: Films were sandwiched between SolidWater^{TM} phantoms at a depth of 5 cm and a backscatter thickness of 15 cm. Irradiations were performed using a 6 MV-FFF beam (Varian TrueBeam^{TM} linac). A 10 x10 cm^2 field size and SSD of 100 cm were used to deliver doses 2, 5 and 8 Gy.
- Proton Irradiation: Film samples were placed between layers of solid water phantoms and were irradiated with proton beam at 5, 8 and 15 Gy using a Mevion S250^{TM} passive scattering proton therapy machine.
- Net optical density was measured using an EPSON 10000XL Scanner. All measurements were performed at different time intervals post-irradiation up to 120 hours.



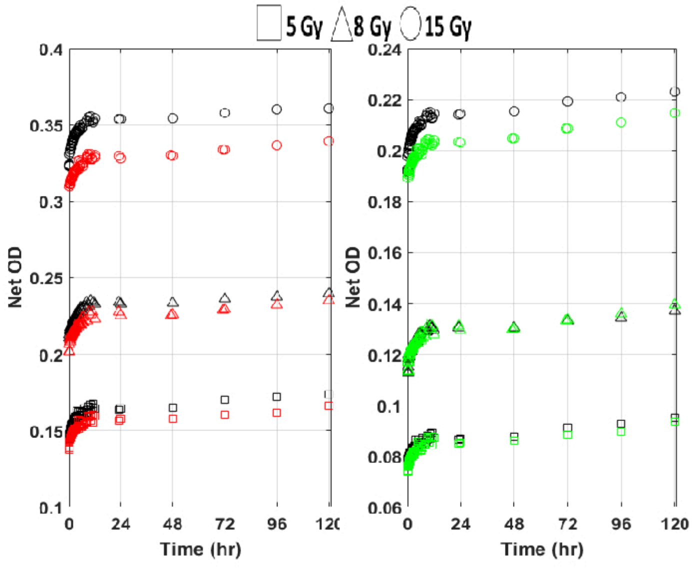


Figure 1: Post irradiation *Net OD* as a function of *Time* at various dose levels for photon-irradiated EBT-XD batch#1 in color channel and EBT-XD batch#2 in black corresponding to the same color channel as channel color of that window.

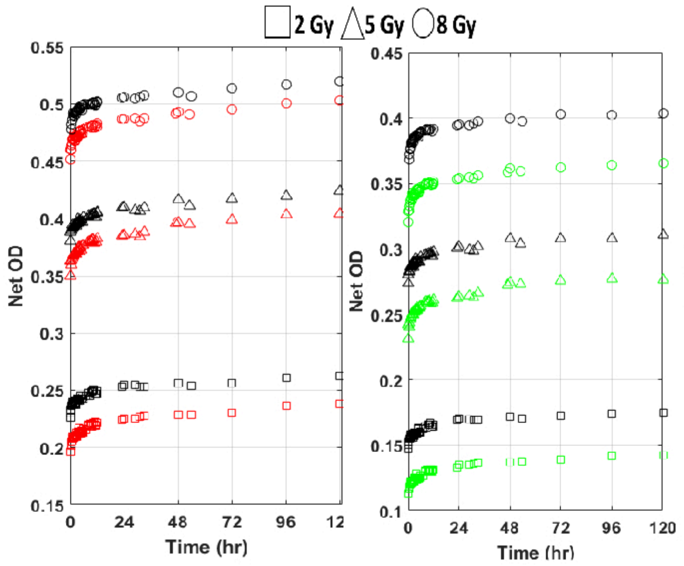


Figure 2: Post irradiation *Net OD* as a function of *Time* at various dose levels for photon-irradiated EBT-3 batch#1 in color channel and EBT-3 batch#2 in black corresponding to the same color channel as channel color of that window.

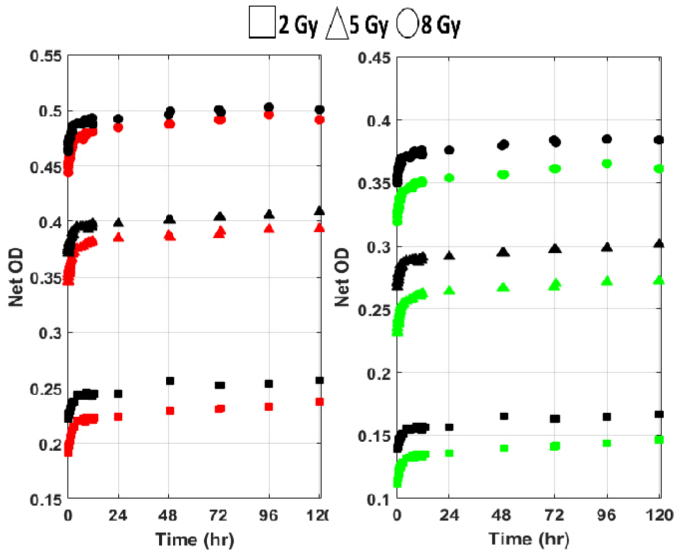


Figure 3: Post irradiation *Net OD* as a function of *Time* at various dose levels for proton-irradiated EBT-3 batch#1 in color channel and EBT-3 batch#2 in black corresponding to the same color channel as channel color of that window.

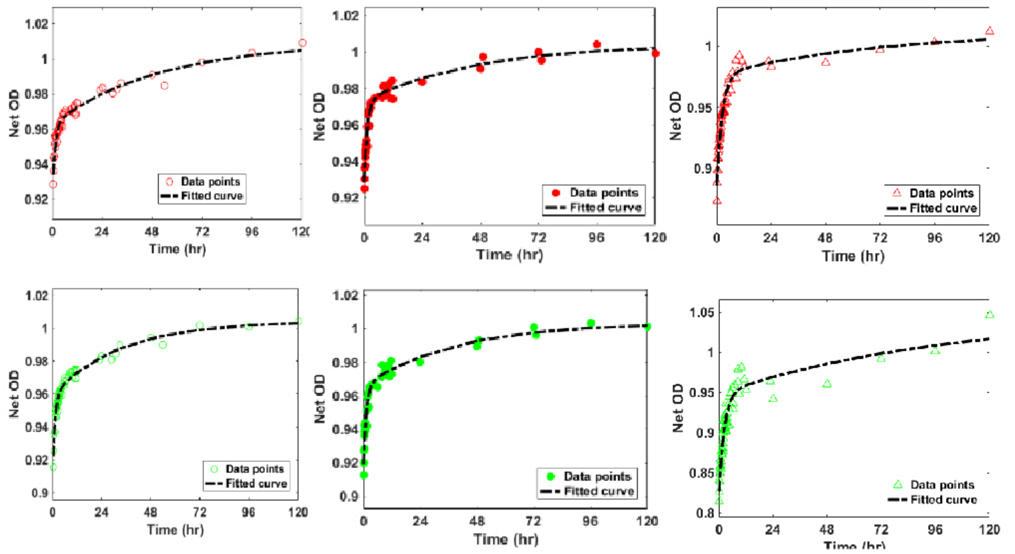


Figure 4: Double exponential curve fitting of *Net OD* (see equation) of red and green channels with respect to *Time* for EBT3 batch#2 irradiated by photon (first column) and proton (second column), and for EBT-XD batch#2 irradiated by photon (third column) at 8 Gy dose level.

RESULTS

In both, photon and proton-irradiated EBT-3 films, the net optical density (Net OD) calculated by subtracting the OD of the film prior to irradiation appears to plateau around 24 hours (Figure 1, 2 and 3). Overall response of the film is uniform for both photon and proton irradiated films. However, proton saturates at higher rate (Figure 3) in comparison to films irradiated by photons (Figure 2), suggesting different mechanisms, and rates of fast and slow of polymerization.

Like previous radiochromic film models, the growth of the optical response was seen to follow a double exponential model with the following equation [1,2]: $OD(t) = OD_S - (C_1 e^{-\frac{t}{T_1}} + C_2 e^{-\frac{t}{T_2}})$ where OD_S is the net optical density reached upon stabilization, which can be set to unity when the data are normalized. OD_S was set to unity by dividing by the average value obtained for either net optical density or net absorbance value for all measurements taken between 24-120 hours. For scanner analysis the red, green, and blue channels were investigated but only the red and green channels were fitted with the double exponential model. The blue channel information suffers from low SNR. The measured data were fit to the double exponential model. Overall goodness of the fit was considered good based on the randomness of the residual.

Additional results indicated that the parameter C_1 and C_2 had a correlation with the dose level. The values of these parameters decreased with increasing doses. This intuitive follows the measured data correctly as the C_1 and C_2 are coefficients of two exponential terms, which would reflect the shoulder of the curve fitted to the observed data. Lower the values of C_1 and C_2, sharper the initial increase of the curve towards stability. In the initial film reading characteristics, the results demonstrated the batch dependency in Net OD values of EBT3 films (Figure 2 and 3). For EBT-XD films, the batch dependency was more prominent at a high dose level compared to low dose levels (Figure 1).

CONCLUSIONS

Overall results demonstrated the growth kinetics of radiochromic films irradiated with proton and photon beams at various dose levels by means of a double exponential model. This double exponential model proposed for previous film models showed to be a good fit, which takes into account that there are multiple rates at which the active layer polymerizes. We anticipate that the C_1 term could model the initial population of radicals generated by the radiation, reacting with a lifetime of T_1 and thus giving rise to the fast component of polymerization. C_2 could be some radical population reached within the films that then allows the slow polymerization proves to begin to dominate. T_2 is the lifetime of the slow component of polymerization.

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