Development of a Modified 3D Radiochromic Dosimeter for Clinical Proton Beams

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Introduction

PRESAGE™ is a three-dimensional polyurethane dosimeter formulated with a halogenated hydrocarbon free radical initiator and leuco dye malachite green. During irradiation, the free radicals generated oxidize the leuco dye to give a radiochromic response with a maximum absorbance at 633 nm which is compatible with commercially available optical CT systems. The dosimeters are nearly tissue equivalent with a density of 1050 kg m-3 and an effective Z of 6.6. PRESAGE™ dosimeters have several advantages over other three-dimensional dosimeters. The dosimeters can be molded into any shape desired and no container is needed to maintain the shape.

The response of the dosimeter to photons up to 16 MeV has been previously described [1,2,3]. Previous studies have also investigated the response of PRESAGE™ to 200 MeV protons [4]. This study reported as large as a 38% under-response in the SOBP region of a clinical proton beam [4]. The purpose of this study was to develop a new formulation of PRESAGE™ that does not under-respond in a proton beam

Materials and Methods

A modified formulation of PRESAGE™ was developed that replaced the reporter molecule used in the original formulation, leucomalachite green (LMG), with a new LMG derivative. The relative stability of LMG and the derivative was determined. Formulations of PRESAGE ™ were manufactured that contained the reporter molecule, polyurethane, and a high % solvent (10%) which promotes color fading after irradiation. Each formulation was placed in a 20 mL vial and irradiated to the same dose. The optical density of the irradiated vials was measured periodically over a 24 hour period on a Hitachi-Perkin Elmer absorption spectrometer at 630 nm.

The response of the dosimeters to protons and photons was also determined. Three dosimeters were made using the original formulation of PRESAGE™ and an additional three dosimeters were made using the LMG derivative. These dosimeters were irradiated in a modulated 250 MeV proton beam providing a 10 cm spread-out Bragg Peak (SOBP). The dosimeters (~ 6 cm in diameter) were positioned in a water tank at a depth corresponding to the middle of the SOBP to provide a uniform dose to the entire dosimeter. The three dosimeters of each formulation were irradiated to doses of 1, 2 and 5 Gy. Three additional dosimeters containing the LMG derivative were irradiated using 6 MV photons to doses of 1, 2 and 5.3 Gy. A pair of parallel-opposed beams was used to produce a uniform dose throughout the dosimeter. One day after irradiation, each dosimeter was imaged using an OCT-OPUS™ laser CT scanner. An in-plane resolution of 1 x 1 mm^2 was used. Dose response curves for both formulations were developed for protons and an additional dose response curve for photons was developed for the formulation containing the LMG derivative.

A proton depth dose curve was measured using a large PRESAGE™ dosimeter (11 cm in diameter and 11 cm in height). The dosimeter was position in a water phantom with the center at a depth of 26.5 cm (as shown in Figure 1). An unmodulated 250 MeV beam was used with a range of 28.5 cm to deliver a maximum dose of 7 Gy. Two additional PRESAGE™ dosimeters were used to develop a calibration curve up to 7 Gy. The dosimeters were irradiated in the plateau region of an unmodulated beam, therefore there was very little dose gradient over the width of the dosimeter.

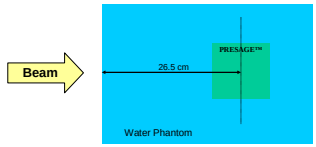

Figure 1. Diagram of setup used to measure proton depth dose using PRESAGE™

Results

	Initial OD	1 hr OD	16 hr OD	24 hr OD
LMG	100%	98%	79%	63%
LMG Derivative	100%	99%	97%	96%

Table 1. The stability of LMG and the LMG derivative over 24 hours (OD values were normalized to the initial OD value).

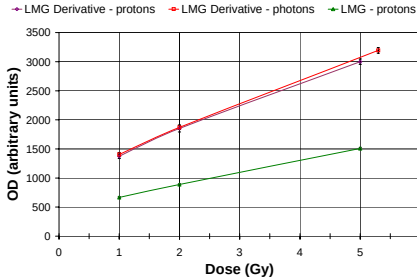

Figure 2. Plot of the dose response of both formulations of PRESAGE™ to protons and the LMG derivative to photons. Error bars represent one standard deviation.

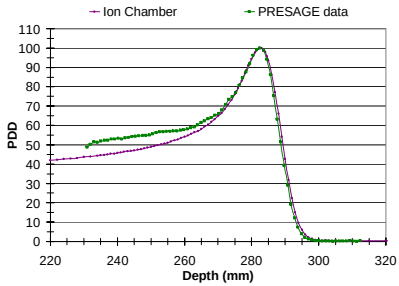

Figure 3. Comparison of the 250 MeV pristine proton depth dose measured with PRESAGE™ and ion chamber.

Discussion

The LMG derivative provided improved stability of the response post-irradiation. The LMG derivative exhibits only a 4% decrease over a 24 hour period, compared to a 37% decrease in the original formulation. When irradiated with protons of the same energy, the response of the dosimeter formulated with the LMG derivative was 52% more than that of the original formulation. Also, the response of the dosimeter containing the LMG derivative was within 3% when irradiated to protons and photons. The data show that the under-response of PRESAGE™ to protons has been corrected by replacing the LMG reporter molecule with a new LMG derivative. The molecular structure of the new derivative was based on the presumption that the under-response in the original formulation was due to shifting of the equilibrium of the colored malachite green form back to the non-colored leuco form when irradiated in high LET beams.

The dosimeters irradiated in the plateau region of an unmodulated proton beam also yield a monotonic dose response, similar to that shown in Figure 2. The response of the dosimeter irradiated in the water phantom was converted to dose using the calibration curve. The PRESAGE™ measured the absolute dose delivered within 3%. The data were normalized at the depth of maximum dose. The density of PRESAGE™ was used to scale the depth of the dose distributions measured in the PRESAGE™ to the water-equivalent depth. This allowed for comparison with ion chamber data measured in water. As shown in Figure 3, there is good agreement between the PRESAGE™ and ion chamber data in the Bragg Peak region. However, the PRESAGE™ overestimates the dose in the plateau region by as much as a 7.4%.

The new formulation of PRESAGE™ has demonstrated potential to be used in proton therapy. Future investigations need to include measurement of modulated proton beams and measurements performed in anthropomorphic phantoms. In addition, a determination of the stopping power should be conducted in order to properly determine the depth of protons in PRESAGE™.

References

1. Adamovics,J. and Maryanski, M.J. "Characterization of PRESAGE: A New 3D Radiochromic Solid Polymer Dosimeter for Dosimetry." Radiat. Prot.Dosimetry, 107-112 (2006).
2. Guo, P.Y., J.A. Adamovics, and M. Oldham. "Characterization of a new radiochromic three-dimensional dosimeter." Med. Phys., **33**, 1338-1345 (2006).
3. Heard, M., A. De La Mora, J. A. Adamovics and G. Ibbott. "Evaluation of a new 3D polyurethane dosimeter for IMRT verification." Med. Phys., **32,** 2167 (2005).
4. Heard, M., J. Adamovics, and G. Ibbott. "Measurement of a 200 MeV proton beam using a polyurethane dosimeter." J. Phys.: Conf. Ser., **56**, 228-230 (2006).

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