Linear Energy Transfer (LET) dependence of BANG® polymer gel dosimeters in proton beams

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Introduction

In clinical radiotherapy, polymer gel dosimeters can provide precise and high-resolution verification of complex three-dimensional dose distributions. Polymer gel dosimetry is based on the radiation-induced polymerization of acrylic monomers infused in a gelatin matrix.[1] This change in gel structure can be observed and quantified using Optical Computed Tomography (OCT).

Proton therapy is becoming increasingly useful as an external beam radiotherapy modality because of its characteristic dose distribution. Proton beams provide a high dose at the end of their range, with their range depending on the energy of the proton beam. Dose deposited to normal tissues or nearby critical organs is minimized because protons have a low entrance dose and a sharp distal fall off at the end of their range. Such unique characteristics enable improved local control, and thus increased dose to the target volume which is highly conformal and homogeneous.

Research has shown a decrease in the response of gel dosimeters in high LET regions of a dose distribution. Dose and LET increase as protons slow down at the end of their range. The aim of this study is to assess the response of various formulations of BANG® polymer gel dosimeters (MGS Research Inc, Madison, CT) in proton beams, particularly in the high LET region.

Methods

Two specific formulations of BANG®1 and BANG®3 polymer gel dosimeters are addressed in this study. The BANG®3 formulation contained methacrylic acid, a single monomer species, as well as a microviscosity agent added during production. The BANG®1 formulation contained bis-acrylamide and acrylamide monomer species in equal concentrations, enriched with 0.2 mM $FeSO_4$. Proton and photon dose response curves for the BANG®3 gel dosimeters were obtained by irradiating one gel dosimeter along the plateau of the 250 MeV proton beam, and the other irradiated with photons at a depth of 5 cm. Each irradiation utilized a water phantom for setup of the gels. The gel dosimeters had a diameter and height of 7.7 cm and 13.7 cm respectively. The irradiation field size for the proton beam dose response curve was 5 cm by 5 cm, and the schematic in Fig. 1 diagrams the irradiation scheme for the dose response curve. The top half of the gel dosimeter was irradiated with 1Gy, and then turned 90 degrees and irradiated with 2 Gy. The couch was moved up vertically so the bottom half of the gel dosimeter was in the treatment field. It was irradiated in the same position with 2 Gy again, then rotated 90 degrees and given 4 Gy. The photon dose response curve was obtained using a Varian LINAC 2100 series. The same irradiation scheme described for the proton dose response curve was used, with doses of 1, 2, 3, and 6 Gy in a 4 cm by 4 cm field given.

A subsequent irradiation using the BANG®1 formulation had the same setup to assess the proton dose response of this gel dosimeter. For this irradiation, doses were given to provide a 0 to 9 Gy dose range for protons, and a gel container with a 12.5 cm diameter and a 17.5 cm height was used.

The gels were then scanned using OCT, and ion chamber measurements for the calibrated 250 MeV proton beam and LINAC were collected in order to assess the gel response at various doses.

Next, Pristine and 4 cm Spread Out Bragg Peak depth dose distributions of a 250 MeV proton beam were evaluated with each formulation using gel containers with the same size as the second proton dose response. The PET plastic containers were centered 27 cm from the entrance of the water tank. Each gel dosimeter contained both the Pristine and SOBP dose distributions for the 250 MeV proton beam. Prescribed doses of 3 Gy and 8 Gy were given to the Bragg Peak for both the Pristine and SOBP for the BANG®3 and the BANG®1 formulations, respectively.

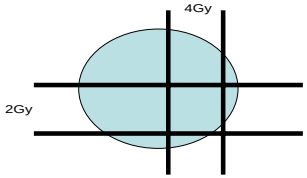

Figure 1. Schematic of the bottom view of the irradiated gel.

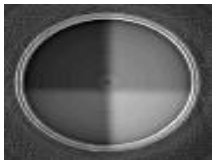

Figure 2. Optical CT scan of gel used for the BANG®3 proton dose response curve. The lightest quadrant on the bottom right represents the highest dose given to the gel, 6 Gy.

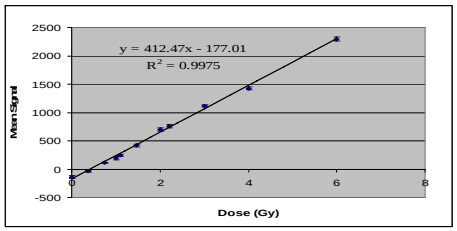

Figure 3. Proton dose response curve of Optical CT signal intensity (attenuation) related to dose for BANG®3. Error bars represent one standard deviation of the signal intensity.

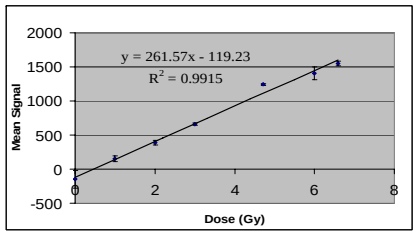

Figure 4. Photon dose response curve of Optical CT signal intensity (attenuation) related to dose for BANG®3. Error bars represent one standard deviation of the signal intensity.

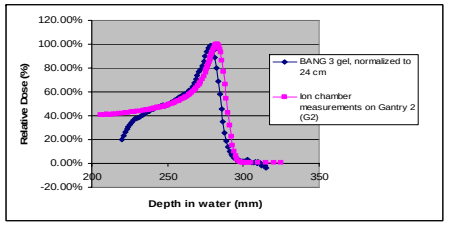

Figure 5. Comparison of the 250 MeV pristine proton depth dose from OCT scans of the BANG®3 polymer gel dosimeter and ion chamber measurements.

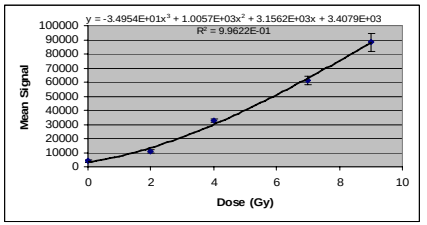

Figure 6. Proton dose response curve of Optical CT signal intensity (attenuation) related to dose for BANG®1. Error bars represent one standard deviation of the signal intensity.

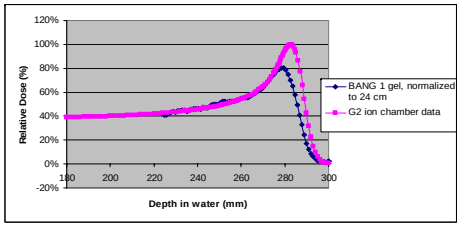

Figure 7. Comparison of the 250 MeV pristine proton depth dose from OCT scans of the BANG®1 polymer gel dosimeter and ion chamber measurements.

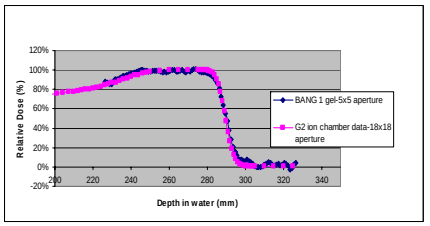

Figure 8. Comparison of the 250 MeV 4 cm modulated proton depth dose from OCT scans of the BANG®1 polymer gel dosimeter and ion chamber measurements.

Results

BANG®3 polymer gel dosimeters had a linear dose response for both protons and photons. A transverse image of an optical CT scan of the BANG®3 used to assess the dose response of the gel is displayed in Fig. 2. As well, the linear relationship of the optical CT attenuation to dose of BANG®3 gels for both proton and photon beams can be seen in Fig. 3 and Fig. 4.

Relative dose was evaluated for the depth dose distributions using the dose response curve obtained in the proton beam. The density of the BANG®3 gel dosimeters, 1.08 g cm^{-3}, was used to scale the depth of the dose distributions measured in the gel to depth in water. In addition, the optical attenuation of the unirradiated gel was used for background subtraction. Figure 5 compares the pristine depth dose distribution obtained from the 250 MeV pristine proton beam for the BANG®3 gel and ion chamber measurements. The BANG®3 depth dose distribution was normalized at 24 cm, and underestimated the absorbed dose at the Bragg peak by 1.3%. The 250 MeV modulated depth dose distribution from the BANG®3 gel reading, with a 4 cm SOBP, did not resemble a modulated proton depth dose distribution. Very little attenuation of the He-Ne laser beam incident on the gel was measured from the photodiode detector of the OCT scanner at the beginning of the depth dose distribution. This yielded a very low entrance dose. As well, poor fall off of the depth dose distribution at the end of the protons' range did not resemble a 250 MeV modulated proton beam.

The proton dose response curve for the BANG®1 polymer gel dosimeters was fitted to a third-order polynomial, shown in Fig. 6. This formulation was assessed in the same way as the BANG®1 gels. Relative dose was evaluated for the depth dose distributions using the proton dose response curve. The depth of the dose distributions measured in the gel to that in water were scaled based on the density of BANG®1 gel dosimeters, 1.04 g cm^{-3}. Furthermore, the optical attenuation of the unirradiated gel was used for background subtraction. The 250 MeV pristine BANG®1 gel and ion chamber depth dose distributions are presented in Fig. 7. The BANG®1gel was again normalized in the plateau region at 24 cm. It underestimated the absorbed dose by 20% at the Bragg Peak. In addition, Fig. 8 displays the BANG®1 gel and ion chamber 250 MeV depth dose distributions for a 4 cm SOBP. The BANG®1 gel dose distribution was normalized to the SOBP, and 8 mm were added to the depth dose distribution; yielding a depth dose distribution that matched the ion chamber measurements.

Conclusions

As we have studied the response of various formulations of BANG® polymer gel dosimeters in proton beams, the BANG®1 gel response from this study has yielded the most promising results. Further work will be completed to better estimate the stopping power of the BANG® gels, to improve the accuracy of the OCT data for the proton dose distributions.

As this research continues, a BANG® gel formulation will be chosen that best corrects for LET dependence. Then a BANG® gel dosimeter will be placed inside the RPC pelvis phantom and irradiated with simple geometries under clinically relevant conditions. The BANG® gel will be used to evaluate the radiation treatment plan calculations for simple cases of surface contour variations and heterogeneities.

References

[1]Back S °A J, Implementation of MRI gel dosimetry in radiation therapy. *PhD Thesis* 1998, Lund University, Malmö.