Initial study of 3D dose verification of multi-field proton therapy treatment along match line with polymer gel detectors

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Abstract. This paper is intended as an initial study for quality assurance benefits from polymer gel detectors to proton therapy treatments. Several gel types were explored for stability from batch to batch. The depth dose distributions in the gels were examined with regard to dose dependences and compared to baseline measurements. The results indicate polymer gel detectors may be able to verify dose in three dimensions along match line for proton therapy treatments.

1. Introduction
The purpose of our study is to examine the dose due to match lines using polymer gel detectors for quality assurance of multi-field proton treatment plans. An advantage of gels is that you have the ability to verify dose in three dimensions. The uses of polymer gel detectors as a tool for radiation dosimetry have been well investigated in the literature [1]. Some of the advantages of gel dosimeter include potential applications of high linear energy transfer (LET) particles and proton therapy [2-4]. In the study we generate a calibration curve to interpret our experimental results on the dose response of the gel from the irradiation of protons.

2. Materials and Methods
We prepared MAGIC (methacrylic and ascorbic acid in gelatin initiated by copper) and MAGAT (methacrylic acid gelatine and tetrakis (hydroxymethyl) phosphonium chlorided) type gels for this study. The gels are prepared at standard temperature and pressure conditions (22°C, 760 mmHg). The Magic gels are composed of 9% gelatin by weight (300 bloom, (Aldrich; Milwaukee, WI), ascorbic acid (2×10⁻³ M, Mallinkrodt; Paris, KY), CuSO₄·5H₂O (8 × 10⁻⁵ M, Aldrich; Milwaukee WI) hydroquinone (1.8×10⁻² M, Sigma; St Louis, MO), and HPLC grade distilled water. The MAGAT Gel was made by mixing gelatin by weight (300 bloom, Aldrich; Milwaukee, WI), HPLC grade distilled water (Sigma Aldrich, and Tetrakis (hydroxmethyl) phosphonium chloride, 80 % sodium in water (Sigma Aldrich). (Table 1)

The MAGIC gels are made by mixing 40 g of gelatine and 320 ml of water in a 500 ml flask. The gelatine is then heated to 55 deg C until the gelatine has completely dissolved and is clear. Then the gel is then cooled to 37 deg C before the following mixtures are added to the gelatine: Hydroquinone (1 gm/ 24 ml H₂O), Ascorbic Acid (0.176/ 25 ml H₂O), and Copper solution (0.01g / 15 ml H₂O). Once all components are added the solution continues to mix until completely clear (approx 2-3 min). The final component, 50 ml of Methacrylic Acid, is added to the mixture and mixes
until homogeneous. The gel is then poured into 20 ml scintillation vials and kept in a closed box to reduce light exposure. The process to make the MAGAT gels is similar to the MAGIC process with different reagents added. We need to allow the gels to congeal at least six hours before irradiating.

| Reagent | Gelatin(300 Bloom) | Methacrylic Acid | Ascorbic Acid | CuSO4:5H2O | Hydroquinone | Distilled Water | Tetrakis |
|---------|---------------------|------------------|---------------|------------|--------------|----------------|----------|
| MAGIC   | x                   | x                | x             | x          | x            | x              | x        |
| MAGAT   | x                   | x                |               |            |              |                | x        |

Table 1: Composition of MAGIC gels and MAGAT gels.

Calibration curves (Figures 1 and 1a) were repeatedly created to determine the stability of the gel processing method. All gels were irradiated at room temperature inside a small water tank in the centre of a 10 x 10 field of view at 100 SSD at 2 cm depth. Due to the availability of the machines the MAGIC and MAGAT gels were irradiated with 6 MV photons for calibration using a 2300 iX (Varian) standard linac.

Using proton beams our study, all gels were irradiated at 2 cm depth with beam line option B5 (R15M10) [proton range of 15 cm, 10 cm modulation] and field size of 10x10 cm² at the Roberts Proton Therapy Center which is housed in the department of Radiation Oncology at the University of Pennsylvania Medical Center.

![MAGIC Calibration Curve](image)
We irradiated a 500ml flask with MAGAT with multiple fields from the proton center. Figure 5 is the Monte Carlo calculated SOBP, in water, generated with the GEANT4 simulation toolkit [5]. The arrow indicates where on the SOBP we took our measurements.

MR scans were performed using Siemens Esperee Magnetrom 1.5 Tesla MRI for dose read-out. We placed the gels within a Magnetrom Head Coil (Syngo MR B15) that has an 8 channel head array. The multi-spin pulse sequence parameters include a TR=8660 ms, slice thickness=2mm, 16
echoes, 26 slices and TE=22.4 ms. We used a dedicated MATLAB program to do pixel-by-pixel calculation of the R2 (=1/T2) values.

3. Results and Discussion
We determined MAGAT was the most practical gel to use based on its consistency and ease of preparation. Figure 2 shows the calibration vials with one slice from the MR scan. From the analysis of the scans using our MATLAB code we were able to calculate a calibration curve (figure 3) from the proton irradiation. For the protons the dose was given with beam line option B5 (R15M10) and dose was delivered from 50 MU to 311 MU. This equation will allow for dose to be calculated for future dose plans. We plan to use the gels to ensure dose to plans like the ones seen below in figure 5 and 6. It is important to ensure dose coverage by using a second check (gels) and ensure the dose is being delivered as planned.

Figure 3: Picture of MAGAT proton calibration vials and corresponding MR images

Figure 4: MAGAT gel - Proton Calibration Curve
4. Conclusions
In this initial study, we developed a consistent method for preparing MAGAT gel and developing a multi-spin pulse sequence for creating R2 maps. The results indicate that the gels have the potential of measuring the dose response from proton beams. Further work is needed in this study to examine the characteristics of the dose response before we use them clinically; especially in match line for proton or photon beam. The hot or cold spots should fall within the calibration curve.

References
[1] C Baldock et al 2010 Phys. Med. Biol. 55 R1
[2] Heufelder J, Stiefel S, Pfaender M et al. Med. Phys. 2003; 30 1235-40
[3] Jirasek A, Duzenli C. Med. Phys. 2002; 29 569-77
[4] Ramm U, Weber U, Bock M, et al. Phys. Med. Biol. 2007; 52 2719-28
[5] S. Agostinelli, et al, Nuclear Instruments and Methods in Physics Research; A 506 (2003) 250-303