High resolution polymer gel dosimetry for small beam irradiation using a 7T micro-MRI scanner

Xuanfeng Ding 1,2 John Olsen 3 Ryan Best 1,2 Marcus Bennett 1,2 Inna McGowin 1,2 Jennifer Dorand 1,2 Kerry Link 3 J. Daniel Bourland 1,2

1 Department of Radiation Oncology, 2 Department of Physics, 3 Center for Biomolecular Imaging, Wake Forest University, Winston-Salem, NC, 27157, U.S.A.

Email: dingx6@wfu.edu

Abstract. The use of small field radiation beams has greatly increased with advanced radiation therapy techniques such as IMRT, rotational IMRT, and stereotactic body radiotherapy. In this work small field 3D dose distributions have been measured with high spatial resolution using polymer gels and 7T micro-MR imaging. A MAGIC (Methacrylic and Ascorbic acid in Gelatin Initiated by Copper) polymer gel [1] phantom was used to capture the 3D dose distributions for two small field (5 x 5 mm$^2$ and 10 x 10 mm$^2$) for a 6MV x-ray beam. High resolution 3D T2 maps were obtained with 7T micro-MRI (0.156mm x 0.156mm x 1mm, MSME pulse sequence). For comparison T2 maps, the gel phantom was scanned in a 3T MRI clinical scanner (0.254mm x 0.254mm x 2mm, FSE pulse sequence). Normalized 3D dose maps were calculated in Matlab. Results show that 7T micro-MRI 3D gel dosimetry measurements are much more stable, less noisy, and have higher spatial resolution than those obtained using a 3T clinical scanner for the same amount of scan time. In general, 3D gel dosimetry results also agree with simultaneously-obtained radiochromic film dosimetry. This study indicates that the MAGIC polymer gel with 7T micro-MRI for 3D dose readout could potentially be used for small radiation beams, including measurements for micro-beams (field size ~ 100um).

1. Introduction:
Dosimetric characteristics can be difficult to determine for small radiation fields used in intensity modulated radiotherapy (IMRT), rotational IMRT, and radiosurgery. In contrast to conventional dosimetry methods (ionization chambers, film, TLD etc.), polymer gel dosimetry is becoming a more important tool for evaluating the small beam 3D dose characteristics. Gel polymerization can be measured by a variety of methods including optical-computed tomography (OCT), x-ray CT, Raman Spectroscopy, Magnetic Resonance Imaging (MRI) and Ultrasound. MRI is a commonly used readout method because it can image the 3D dose distribution in both homogeneous and non-homogenous (e.g. presence of bone) media, and provides high spatial resolution compared to other 3D gel imaging modalities. Current clinical 1.5T and 3T MRI systems are capable of scanning a gel phantom in about one-half hour with finest spatial resolution of about 0.25-0.5mm$^3$. However, for very small radiation fields (<1cm diameter) or micro-beams (<1mm diameter) captured in polymer gel, increased image resolution and signal-to-noise ratio (SNR) are critical and may be afforded by using MR field strengths greater than 3T. MR scan time is also important for gel dosimetry. In this initial work, we compare the performance of 3T and 7T MR imaging for the 3D dose readout of a MAGIC polymer gel for two small field (10 x 10 mm$^2$ and 5 x 5 mm$^2$). Results show that the 7T micro-MRI dose image is more stable and has less noise compared to the 3T clinical MR dose image using the same scan time.
2. Methods and Materials:

2.1. Gel preparation:
The formula of the normoxic MAGIC polymer gel is based on Fong et al in 2001 [1]. These gels are able to be prepared under normal atmosphere conditions (e.g. in-air) instead of in a special oxygen free glove box. The chemical ingredients are commercially available (gelatin swine skin [9% (w/w) 90g]; methacrylic acid [4%(w/w) 40g]; copper(II) sulfate pentahydrate [0.025g], ascorbic acid [0.3522g (2mM)], (all available from Fisher Scientific); and deionized water). The MAGIC gel was instilled into 5cm diameter plastic tubes and sealed with plastic wrapper to prevent outside oxygen from entering. Then, the completed MAGIC gel phantom was stored in a refrigerator (4°C) to set overnight before irradiation.

2.2. Polymer gel and radiochromic film irradiation
Small field irradiation was performed using a 6MV X-ray beam from a 2100 SCX clinical linear accelerator (Varian Medical Systems, Palo Alto, CA). Two small fields 10 x 10 mm$^2$ and 5 x 5 mm$^2$ were defined using symmetrical collimator jaws. The gel phantom was placed on the treatment table with the source-to-surface-distance (SSD) set to 100cm. In this work, we use Gafchromic EBT2 radiochromic film (ISP Technologies, Wayne, NJ) as a comparison to the gel dosimeter. Radiochromic film was handled using gloves to reduce the possibility of damage and contamination according to AAPM TG 55 [3]. The exposed radiochromic films were scanned using an Epson 10000XL scanner 20 hours after irradiation.

2.3. MR imaging and parameters:
A 7T micro-MR scanner (Bruker Corporation, Billerica, MA) was used for high resolution gel dosimeter reading (Figure 1). The high magnetic field strength provides images with very high resolution and signal to noise ratio (SNR) compared to the 1.5 T and 3 T clinical scanners typically used. However, the 7T micro-MR scanner is limited by its core space and special RF coil design, and as a result the cylindrical gel phantom size for the 7T MRI scanner could not exceed 10 cm in diameter. Moreover, due to the limited amount of B0 homogeneity in the scanner center, only a single sample can be scanned at a time. As a result, the gel container shape and size is very important consideration for use of the micro-MR high resolution scan.

The irradiated gel phantom was first scanned in the 7T MR using a linear birdcage volume coil (Bruker Corporation, Billerica, MA) with these parameters: Field of View (FOV) = 4cm Slice Thickness=2mm interslice distance = 5mm; Matrix size = 256 x 256; pixel size = 0.156mm; TE = 30, 60 … 300 ms and TR = 3330ms (Figure 2). Total scan time was about 30mins. Next, the gel phantom was scanned at the same room temperature using a 3T MRI GE signa® EXCITE™ clinical scanner (GE Healthcare, Milwaukee, WI) with 8-channel head coil. An alternative pulse sequence to MSME, Fast-Spin-Echo (FSE) was used with parameters: FOV = 6.5cm; matrix size = 256 x 256; TE = 50, 100… 500; TR = 4000 ms; NEX = 1; slice thickness = 2 mm and pixel size = 0.254mm x 0.254mm

![7 Tesla Magnet Console Monitor](image)

**Figure 1.** a) 7T Bruker micro-MR scanner setup for gel dosimeter. b) Gamma radiosurgery irradiated gel phantom scanned at 7T with the MSME pulse sequence for T2 maps calculation.
3. Results:
Polymer gel MR images are shown for 7T and 3T field strengths in Figure 2. and demonstrate higher image fidelity and less noise at 7T (Fig. 2a) vs 3T (Fig. 2b). Radiochromic film, obtained simultaneously at the time of gel irradiation, documents the field sizes (Fig. 2c). Dose profiles are shown for the 7T and 3T readouts and the radiochromic film(Figs. 2 d-e).

![Figure 2. a) Gel phantom R2 map, axial plane, calculated from 7T MRI scan, pixel size = 0.156 mm. b) Gel phantom R2 map, axial plane, calculated from 3T MRI scan, pixel size = 0.254mm. c) Radiochromic film irradiated by 5 x 5 mm² and 10 x 10 mm² fields. d) dose profile of 10 x 10 mm² 6MV beam at depth of 1.5cm. e) dose profile of 5 x 5 mm² 6MV beam at depth of 1.5cm.](image)

4. Conclusions:
7T micro-MRI gel imaging greatly improves the dose measurement in both accuracy and spatial resolution compared to 3T MRI with a clinical scanner. At 7T field strength, 3D dose distribution images with voxel size of 0.156mm x 0.156mm x 1 mm were achieved within 30 minutes of scan time using a 150mm inside diameter linear birdcage volume coil (max gradient 200mT/m). A higher resolution (<50um x 50um x 1mm) could be achieved within a 2 hour scan time using a 35mm inside diameter quadrature birdcage volume coil (max gradient 1000mT/m). This approach could be potentially used to measure a micro-beam (~100um) dose distribution.

References:
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