Magnetic Resonance Elastography of Polymer Gel Dosimetry Phantoms

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Introduction: Magnetic resonance imaging dependent polymer gel dosimetry is a technique that offers unique advantages for implementing increasingly complex radiotherapy procedures, due to the high spatial resolution and volumetric dosimetry capabilities. The technique involves the estimation of radiation dose distribution based on the changes in MR relaxation parameters caused by radiation induced polymerization (1). Magnetic Resonance Elastography (MRE) is a technique for quantitatively assessing the stiffness of materials by imaging the propagation of externally induced mechanical shear waves(2). Since radiation causes polymerization of monomers in polymer gel dosimeters, we hypothesized that the stiffness of an irradiated region would quantitatively reflect the radiation dose to the gel. The purpose of this work was to test this hypothesis in a series of polymer gel phantoms by investigating the correlation between the absorbed radiation dose and MRE-assessed stiffness. If the hypothesis is correct, this would provide an independent approach for polymer gel-based radiation dosimetry.

Materials and Methods: A 1.5-T whole body scanner (GE Signa, Milwaukee, WI) was used in all of the experiments. A series of cubic phantoms of 236 cm^3 were made using the MAGIC dosimetry gel (3) and were irradiated with a conventional 1.25 MeV Theratron 780C Cobalt-60 radiation therapy unit (MDS Nordion, Kanata, Canada). A cylindrical region (radius 3 cm) of the phantom was irradiated, with the phantom remaining stationary and the Co-60 unit gantry rotating (180^o) around the isocenter using parallel-opposed fields to guarantee dose distribution homogeneity. The radiation dose ranged from 0 to 50 Gy with 10 Gy steps. MR Relaxometry (4) images depicting the transverse relaxation parameter (R_2 = $1/T_2$) of these irradiated phantoms were acquired with a double echo spin-echo sequence with echo times (TE) of 20 and 100 ms and a long repetition time (TR = 4,000 ms). For acquiring MRE data, mechanical shear waves of frequency 250 Hz were introduced in these phantoms and the propagation of these waves was imaged using a gradient echo based pulse sequence with one cyclic motion encoding gradient pair. Other relevant imaging parameters were FOV = 14 cm, acquisition matrix = 256x64, frequency encoding direction = SI, TR/TE = 100/21 ms and slice thickness = 10 mm. From these wave propagation images, elastograms were generated using a Local Frequency Estimation algorithm with application of spatio-temporal directional filters (5).

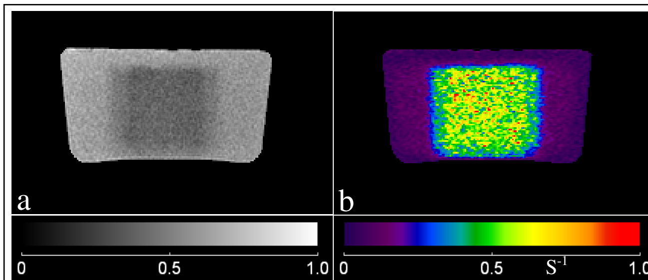

Figure 1 : 1a. Conventional MR magnitude image and 1b. Normalized Relaxometry image of the 50 Gy phantom depicting R2.

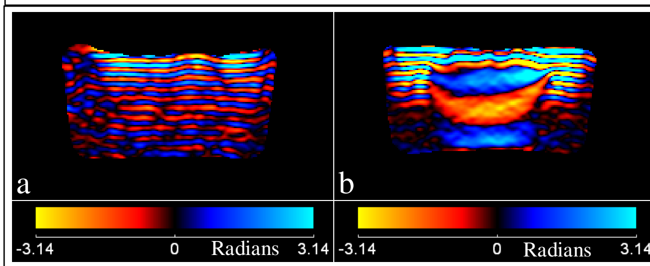

Figure 2: 2a. Single wave image of the control phantom. 2b. Single wave image of the 50 gray absorbed dose phantom where the wavelength lengthening in the stiff region is easily visible.

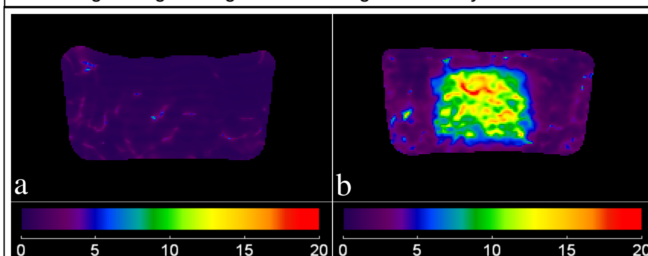

Figure 3: 3a. Stiffness map of the control phantom. 3b. Stiffness map of the 50 gray absorbed dose phantom clearly showing the stiff irradiated region (units are in kPa).

Results and Discussion: Figure 1a shows a spin echo MR magnitude image of the 50 Gy absorbed dose phantom with TE at 20 ms, where the presence of the irradiated region could be identified due to the change in T2. It becomes clearly visible in the normalized relaxometry image of the phantom shown in figure 1b that maps the R2 of the phantom. Figure 2 shows one of the wave propagation images obtained from the elastography experiments for the control phantom with no irradiation (2a) and the 50 Gy absorbed dose phantom (2b). A wavelength difference between the 50 Gy and control phantoms is clearly apparent in the irradiated region. The wavelength is longer in the irradiated region than the non-irradiated region of the same phantom, due to increased stiffness in radiated gel. The corresponding elastograms for the control and the 50 Gy absorbed dose phantoms are shown in figures 3a and 3b respectively. It is evident that the stiffness of the irradiated region is higher than that of the non-irradiated region in the same sample or the control phantom due to the conversion of monomers to polymer aggregates upon irradiation. Comparing the stiffness estimate map and the normalized relaxometry map of the 50 Gy phantom (1b), it can be seen that they are very well correlated. Figure 4 shows the stiffness values of the phantoms as a function of the absorbed dose and the increase in stiffness of the irradiated region as the radiation dose increases is clearly evident.

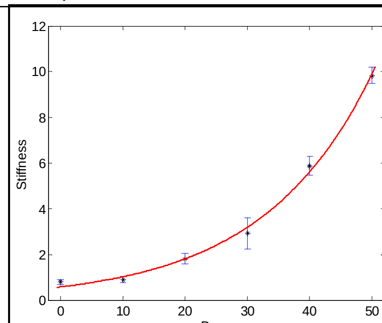

Figure 4: The plot of stiffness(kPa) against the absorbed dose(Gy).

Conclusion: The results show that the stiffness of a polymer gel dosimeter is directly correlated to the applied radiation dose. Given this correlation, it is possible to use Magnetic Resonance Elastography to estimate radiation dose distribution through the measurement of shear stiffness of materials. We conclude that MRE provides an independent method for measuring radiation does distributions in polymer gel dosimetry constructs. The results provide motivation for further studies to compare the accuracy and dose estimation ranges of relaxometry and elastography-based 3D gel dosimetry methods.

References :(1) Maryanski et al., *Phys Med Biol*. 39: 1437-1455, 1994. (2) Muthupillai et al., *Science* 269: 1854–1857 1995. (3) Fong et al., *Phys Med Biol.* 46: 3105–3113, 2001. (4)Carneiro et al., *Braz J Phys* 36: 9-15, 2006. (5) Manduca A et al., *Med Imag Anal*. 5: 237-254, 2001