Magnetization transfer in polymer gel dosimeters

Heather M. Whitney, Daniel F. Gochberg and John C. Gore
Institute of Imaging Science, Vanderbilt University, Nashville, TN, USA

1. Introduction
Radiation dose distributions in polymer gel dosimeters can be quantified using various MRI methods. Currently, measurements of R2 are in common use for measuring doses. The dose response mechanism is believed to involve magnetization exchange between the polymer formed by radiation and the solvent in the gel. We have used quantitative measurements of magnetization transfer (MT) to characterize polymer gels before and after irradiation to better understand their dose response, and to explore the potential advantages of imaging based on MT.

2. Theory
A simple model of polymer gels considers them to have two proton pools, coupled by exchange: the free, mobile solvent protons, and a second pool of relatively immobile protons that result from polymerization. Specific formulations of gels may differ, but the underlying idea is the same; as the gels are irradiated, the size of the bound pool increases, and as a result of magnetization exchange processes, the overall proton R2 increases. This model affords useful insights into the relevance of both particle rigidity and chemical exchange on relaxation in polymer gels. The precise nature of these exchange mechanisms, and how they depend on the gel composition, have not been established.

3. Materials and Methods
MAGIC gels were manufactured as described previously [1]. Samples were irradiated 24 hours after manufacture in sets of three to increasing dose levels. After an additional 24 hours, MT measurements were made using the steady state off resonance irradiation technique described by Henkelman et al [2] using a benchtop Maran imaging system at 0.5T. Offset frequencies ranged from 0 to 216 kHz, logarithmically spaced, and the field power varied in 6 steps, from 987 to 34264 rad/sec. A simple inversion recovery experiment was also performed to collect T1 data for each sample. The data were fitted using a linear least-squares method to the model proposed by Henkelman et al, assuming a super-Lorentzian absorption lineshape to extract a number of parameters. This work focuses on the parameter $R$, the fundamental rate constant of spin exchange.

4. Results
Previous experiments to characterize $R$ in polymer gel dosimeters showed the rate constant to be independent of dose for BANG gels, a hypoxic dosimeter, but clearly dependent on dose for MAGIC gels, a dosimeter prepared in normoxic conditions [1, 3]. These previous results measured the transient response of the gel to an inversion pulse, which is a different method to our steady-state
measurements. Nonetheless, our results show data similar to [3] for the MAGIC formulation, at least to approximately 20 Gy. The rate of MT appears to increase with dose, which implies there are changes other than a simple increase in the number of polymerized particles produced by radiation.

**Figure 1.** Sample results of curve fitting, for a dosimeter irradiated to 15 Gy. Magnetization is plotted versus offset frequency, varied by field strength.

| Offset Frequency (Hz) | Experimental Data | Fit to Model |
|-----------------------|-------------------|--------------|

**Figure 2.** $R$ vs. dose, comparison of results from previous experiments and the one discussed here. $R$ is similar in both experiments, up to approximately 20 Gy.
5. Conclusions
The steady state measurements confirm that MT occurs in the polymer gel and the rates appear to be dose dependent in MAGIC gels. The variation of the other model parameters with dose are being further evaluated but should provide additional insights into the dose response of polymer gels that will be useful for designing better gels and more sensitive imaging methods.

6. References
[1] Gochberg D F, Fong P M and Gore J C 2003 A quantitative study of magnetization transfer in MAGIC gels Phys. Med. Biol. 48 N277-N282
[2] Henkelman R M, Huang X M, Xiang Q S, Stanisz G J, Swanson S D and Bronskill M J 1993 Quantitative interpretation of magnetization transfer Magn. Reson. Med. 29 759-766
[3] Gochberg D F, Fong P M and Gore J C 2001 Studies of magnetization transfer and relaxation in irradiated polymer gels - interpretation of MRI-based dosimetry Phys. Med. Biol. 46 799-811