Measurement of particle size in polymer gel dosimeters using spectrophotometry

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

1. Purpose
Polymer gel dosimeters have proven to be useful for three-dimensional radiation dosimetry in clinical radiation therapy. However, more study and development work is needed to quantify and further understand the dose response mechanism, with the goal of improving the dosimeters. In this work we seek to determine the diameter of the polymer particles formed upon irradiation, for a range of irradiation dose rates. It is expected that this information will be used to further understand the actual formation of polymer in the gelatin matrix, and how it affects the relaxation of water in the dosimeter as measured with magnetic resonance imaging or optical methods.

2. Materials and Methods
MAGIC-2 gel dosimeters were made using standard preparation techniques [1]. The specific formulation is comprised of 87% water, 4% methacrylic acid, 9% gelatin, [Cu²⁺] = 1.738 x 10⁻⁵ M, and a ratio of ascorbic acid to [Cu²⁺] of 1000:1. After preparation, the gels were poured into plastic cuvettes and sealed with plastic toppers. The boundaries of the cuvettes and toppers were dipped in sealing wax to prevent leakage of oxygen into the gel. The gels were stored in a closed styrofoam container, refrigerated overnight, and irradiated the next day using a Therapax orthovoltage x-ray unit. Samples were refrigerated for three weeks and then analyzed with a UV-VIS spectrophotometer. Absorbance versus wavelength was measured for a wavelength range of 290 through 900 nm.

Results were analyzed using a method previously implemented with BANG gels [2]. Assuming that the polymer particles formed in the MAGIC gel are spherical, that their index of refraction is 1.5, and light absorption is negligible, the particle diameter can be determined by the relation

\[ 2a = \frac{(ka)_{\text{max}}}{n \pi} \lambda_0 \]

where \(a\) is the maximum particle radius, \(k\) is the wave number in the medium, \(ka_{\text{max}}\) is the value of \(ka\) at which \(Q_{\text{sc}}\), the Mie-Debye efficiency factor, is maximized, \(\lambda_0\) is the wavelength at which maximum turbidity is observed, and \(n\) is the index of refraction. From the literature, \(ka_{\text{max}}\) is considered to be 4.34 [3]. Particle sizes were determined for the MAGIC gel dosimeters as a function of dose, over a range of dose rates.
Figure 1. Absorbance spectra for four dosimeters and a single dose rate.

Figure 2. Absorbance versus dose for a single dosimeter.
3. Results
The results for a sample spectrophotometric experiment are shown in Figure. Absorbance spectra are given for four different dose levels. The wavelength of maximum turbidity is chosen from these data. Figure 2 displays the measured absorbance versus dose for a given dosimeter, measured at three different wavelengths of light. In each case, absorbance increases with dose. Figure 3 shows the results for maximum particle diameter versus dose for a range of dose rates from 0.22 to 2.60 Gy/min. Particle size varied from 270 to 334 nm over a dose range of 0 to 40 Gy. There is a clear increase of particle size with dose, but the correspondence of this behaviour to dose rate is not yet clear.

4. Conclusions
These experiments show an increase in the diameter of polymer formed in the MAGIC-2 gel dosimeter associated with increased applied dose. Further studies will compare these data to molecular weight measurements.

5. References
[1] Fong P M, Keil D C, Does M D, Gore J C 2001 Polymer gels for magnetic resonance imaging of radiation dose distributions at normal room atmosphere Phys. Med. Biol. 46 3105-3113
[2] Maryanski M J, Zastavker Y Z and Gore J C 1996 Radiation dose distributions in three dimensions from tomographic optical density scanning of polymer gels. 2. Optical properties of the BANG polymer gel Phys. Med. Biol. 41 2705-2717
[3] Wickramasinghe N C 1973 Light Scattering Functions for Small Particles New York: John Wiley & Son, Inc
Figure 3. Calculated maximum particle diameter.