Polymer gel dosimeters with reduced toxicity

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1. Introduction
Polymer gel dosimetry is a promising technique to verify 3-D dose distributions delivered by radiotherapy equipment. Polyacrylamide gel (PAG) dosimeters, which are the most studied polymer gel dosimeters, consist of the co-monomers acrylamide and N,N'-methylene-bisacrylamide dispersed in an aqueous gelatin matrix \cite{1}. Valuable advantages of the PAG-MRI dosimetry system, compared with other gel dosimeters to date, include tissue equivalence, spatial stability and reproducibility of the 3-D dose-response. Despite the promising results, however, clinical use of polymer gel dosimeters has been limited. Monomer toxicity and oxygen sensitivity make PAG hazardous and inconvenient to use, and there still remain fundamental complications that can lead to incorrect dose measurements \cite{2}. The oxygen sensitivity of PAG dosimeters was addressed by using the antioxidant tetrakis (hydroxymethyl) phosphonium chloride (THPC) \cite{3}.

In this work, potential new monomers were evaluated for use in new dosimeters that are safer and therefore more convenient to use than PAG. Acrylamide is a severe neurotoxin, and a suspected human carcinogen and teratogen that is readily absorbed through the skin \cite{4}. Three new polymer gel recipes were investigated using less toxic monomers with chemical structures similar to acrylamide (Figure 1). The dose-response of the 6\%T, 50\%C dosimeters were analysed using NMR and optical methods, for conditions of varying dose, dose rate, time post-irradiation, and temperature during irradiation and scanning.

2. Material and Methods
Details of the experiments are described by Senden \textit{et al} \cite{5}. All of the gel dosimeters studied contained gelatin (5 wt\%), monomer (3 wt\%), crosslinker N,N'-methylene-bisacrylamide (3 wt\%) and antioxidant tetrakis (hydroxymethyl) phosphonium chloride (10 mM). The gel components were mixed in water under normal atmospheric conditions inside a fume hood. Irradiations were performed approximately 3 hours post-manufacture on a MDS Nordion T-780 Cobalt-60 unit (MDS, Inc.) using a 10x10 cm\textsuperscript{2} field at 2.7 Gy/min and 21 °C (unless noted otherwise). Transverse relaxation rates ($R_2 = 1/T_2$) were determined using a CPMG pulse sequence on a Maran 20/35 bench top NMR spectrometer (Oxford Instruments, Ltd.). The measurements were performed at various times post-irradiation and at different temperatures. Optical attenuation coefficients of the gel samples were determined using an in-house built apparatus with HeNe laser at 630 nm and a photodetector \cite{5}.
3. Results and Discussion

Dose-response (R2) curves were obtained at 24 hours post-irradiation for the 6 %T, 50 %C gel dosimeters (Figure 2). The responses of the NIPAM/Bis and PAGAT gels are qualitatively very similar in the lower dose region. The R2-dose sensitivity of the NIPAM/Bis gel dosimeter is at least as large as for the PAGAT gel, and is quasi-linear over a larger dose range. The dose-sensitivities of the DAAM/Bis and NVF/Bis gels are significantly lower than NIPAM/Bis and PAGAT.

A preliminary investigation was done to assess the sensitivity of the new polymer gel dosimeters to external factors such as time post-irradiation, dose rate, and temperature during irradiation and imaging. Temporal instability was apparent in the responses of all of the dosimeters, but most of the effects occurred within the first 24 hours after irradiation (data not shown). Furthermore, it was shown that changes in the temperature during irradiation (Figure 3) and in the dose rate (data not shown) have only a minimal effect on the R2 of NIPAM/Bis gel within the ranges considered.

![Figure 1. Chemical structures of the different monomers used.](image1)

![Figure 2. Dose-response (R2) curves of 6 %T, 50 %C NIPAM/Bis (■), DAAM/Bis (▲), PAGAT (♦) and NVF/Bis (●) gel dosimeters determined 24 hours post-irradiation at 21 °C. The open symbols are for replicate experiments done on a different day.](image2)
Figure 3. Dose-response ($R_2$) curves of 6 %T, 50 %C NIPAM/Bis gel dosimeters determined at 21 °C, 72 hours post-irradiation. Irradiations were performed at temperatures of 15 °C (▲), 20 °C (■) and 25 °C (●). Error bars (95%) are shown, assuming that the variance is the same as of the dose-response curves in Figure 2.

Figure 4 shows the optical attenuation coefficient at 630 nm vs. dose plot for the three new polymer gel dosimeter recipes. The optical responses of the NIPAM/Bis and PAGAT gel dosimeters...
are very similar. More comprehensive data are expected using an optical CT unit recently acquired for polymer gel dosimetry [6].

4. Conclusions
The NMR and optical dose-response behaviour of different polymer gel dosimeter recipes were assessed under various controlled conditions. Promising results were obtained using PAGAT-like polymer gel dosimeters with less toxic N-isopropylacrylamide (NIPAM) in place of acrylamide. The R2- and optical- dose response were shown to be similar to PAGAT, with high dose-sensitivity and low dependence on changes in the dose rate and irradiation temperature (within the ranges considered). Future work should include the optimization of the NIPAM/Bis gel dosimeter. It will also be important to investigate the spatial resolution using non-uniform irradiation to determine whether NIPAM/Bis gel is a competitive replacement for current acrylamide-based dosimeters.

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6. References
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