Do saccharide doped PAGAT dosimeters increase accuracy?

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Abstract. To improve the dosimetric accuracy of normoxic polyacrylamide gelatin (PAGAT) gel dosimeters, the addition of saccharides (glucose and sucrose) has been suggested. An increase in R_2-response sensitivity upon irradiation will result in smaller uncertainties in the derived dose if all other uncertainties are conserved. However, temperature variations during the magnetic resonance scanning of polymer gels result in one of the highest contributions to dosimetric uncertainties. The purpose of this project was to study the dose sensitivity against the temperature sensitivity. The overall dose uncertainty of PAGAT gel dosimeters with different concentrations of saccharides (0, 10 and 20%) was investigated. For high concentrations of glucose or sucrose, a clear improvement of the dose sensitivity was observed. For doses up to 6 Gy, the overall dose uncertainty was reduced up to 0.3 Gy for all saccharide loaded gels compared to PAGAT gel. Higher concentrations of glucose and sucrose deteriorate the accuracy of PAGAT dosimeters for doses above 9 Gy.

1. Introduction

In the last decades, normoxic polymer gels have been investigated as a device for three dimensional dosimetry [1]. Radiation-induced polymerisation of contained monomers reduces the spin-spin relaxation time (T_2) in a nuclear magnetic resonance (NMR) read-out. This increase in R_2 is proportional to the dose delivered to the polymer gel during irradiation [2]. It has been stated that normoxic PolyAcrylamide Gelatin gels fabricated at ATmospheric conditions (PAGAT-gels) show a superior performance with respect to spatial integrity, temperature sensitivity, dose-rate dependence and radiological water equivalence compared to other polymer gels [3, 4]. Nevertheless, an extensive study of the sources of uncertainty of PAGAT polymer gel dosimeters has pinpointed the temperature of the PAGAT gel during scanning as a major source of inaccuracies [5]. This current study focuses on the improvement of the accuracy of PAGAT gels by adding saccharides. The uncertainty was determined taking into account both the change in dose sensitivity and the temperature sensitivity. According to Yoshioka *et al* [6], the dose sensitivity of PAGAT gels is improved by adding sucrose in different concentrations. Furthermore, studies conducted by Zhu *et al* [7] and Ding [8] confirmed an increase in dose sensitivity of methacrylic acid-based polymer gels (MAGIC) by adding glucose. However, the increase in dose sensitivity by adding saccharides does not necessarily improve the overall dosimetric accuracy, if the temperature sensitivity of the gel during read-out is also increased proportionally. The temperature sensitivity is therefore as important as the dose sensitivity. Therefore,

PAGAT gels with saccharides additives were irradiated to a range of doses, in order to investigate whether the expected increase in dose sensitivity is correlated with an overall reduction of the dose uncertainty caused by temperature dependence. A NMR-relaxometer was utilized in order to obtain overall relaxation times.

2. Materials and methods

2.1. Gel fabrication

Thirty PAGAT gel samples were fabricated and divided into five sets. The first set of samples consisted of pure PAGAT gel for comparison reasons. In a second and third set, 10% and 20% glucose were added, respectively. In a fourth and fifth set 10% and 20% sucrose were added. The remaining ingredients of the gel were: 6% (w/w) gelatin, 3% (w/w) N,N'-Methylene-bis-acrylamide (Bis) as a crosslinker monomer, 3% (w/w) acrylamide (Aam) and 10 mM tetrakis(hydroxymethyl) phosphonium chloride (THP) as an antioxidant. A stock solution was produced with these ingredients according to the procedure described in [9]. After splitting the stock solution into five equal parts, the corresponding amounts of water, sucrose and glucose were added. The THP was then added and the liquid gel was poured into 6 glass tubes for NMR-measurements. The upper part of the glass tubes were subsequently filled with nitrogen gas to prevent oxygen from penetrating the gel, inhibiting polymerisation. All the samples were stored in the refrigerator between 0.5 and 2 hours before irradiation.

2.2. Irradiation

A Varian 21 iXs linear accelerator (Varian Medical Systems) producing 6 MV photons was used to irradiate all gel samples. Each sample was irradiated with the tube axis perpendicular to the beam axis using a 12×12 cm^2 field at a depth of 6.8 cm in a special solid water equivalent phantom. The source to surface distance (SSD) was 100 cm and the sequentially delivered doses (D) were 2, 4, 6, 9 and 13 Gy for the different samples with a dose rate of 4.84 Gy/min. The sixth sample of each set was left unirradiated.

2.3. NMR T_2-measurements

The overall T_2-value of each test tube at different temperatures was measured using a NMR-minispec mq20 analyzer (Bruker Optik GmbH) with a magnetic field strength of 0.47 T. The echo time spacing was chosen to be 0.6 ms for all measurements. Between 1,000 and 10,000 data points were acquired depending on the corresponding spin-spin relaxation time (T_2). An average of 4 scans of the measured magnetisation was fitted to a mono-exponential function to obtain a T_2-value. The sample temperature was controlled before and during the read-out process using a thermostatic water bath. The temperature within the gel sample was measured with a fiber optic thermometry system (Neoptix, Inc.). The accuracy of the temperature recording was ± 0.2 °C. Each sample was measured twice for each water bath temperature. In a time period between 16 and 45 hours after irradiation, all samples were scanned at subsequent temperatures ($T \approx 6$, 14, 18, 23 and 28 °C). At the end, all test tubes were scanned again at the lowest temperatures in order to detect possible changes in T_2 caused by post-polymerisation of gels.

3. Results and discussion

After an interpolation of R_2-values for specific temperature values to facilitate comparison, the dose-R_2 response relations of five different gels at room temperature (T = 20 °C) were plotted and are shown in figure 1. The fitting of the R_2-values indicates a mono-exponential dose-R_2 relation: $R_2(D) = A_D \cdot \exp(B_D \cdot D) + C_D$, where A_D, B_D and C_D are exponential fitting parameters. A significant increase in dose-R_2 response for samples with glucose or sucrose compared to conventional PAGAT gel samples is observed. The slope of the dose-R_2 response around 0 Gy is especially increased for samples with 20% glucose and sucrose. At 20 °C, the slope is increased by a factor of approximately 9

for 20% glucose, a factor of 7 for 20% sucrose and a factor of 3 for 10% glucose and 10% sucrose compared to PAGAT gel. The temperature dependence of the dose-R_2 response relation can be seen in figure 2 for PAGAT gel and PAGAT gel with 20% glucose.

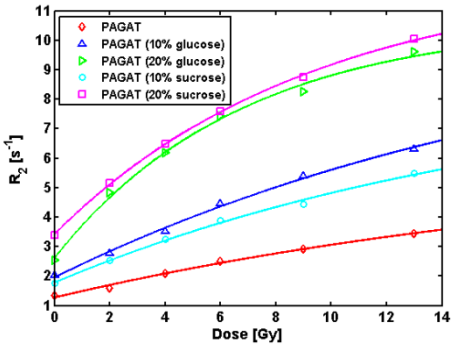


Figure 1. R_2-dose plots at room temperature (T = 20 °C) for different types of gels fitted to mono-exponential equations.

Besides other less dominant sources of uncertainty which were not considered in this experiment, the mono-exponential temperature dependence of R_2 ($R_2(T) = A_T \cdot \exp(B_T \cdot T) + C_T$, with fitting parameters A_T, B_T and C_T) leads to an uncertainty of the subsequently determined dose in an irradiated 3D phantom. This dose uncertainty due to temperature changes (U_D) during the read-out process at a specific temperature can be calculated according to equation (1) and is dependent on the delivered dose.

$$\square_{\square}(\square,\square) = \frac{\Delta\square}{\Delta\square}(\square = \square_0) = \left(\frac{\square\square_2(\square,\square)}{\square\square} \Big/ \frac{\square\square_2(\square,\square)}{\square\square}\right) = \frac{\square_{\square} \cdot \square_{\square} \cdot \exp(\square_{\square} \cdot \square_0)}{\square_{\square} \cdot \square_{\square} \cdot \exp(\square_{\square} \cdot \square)} \qquad (1)$$

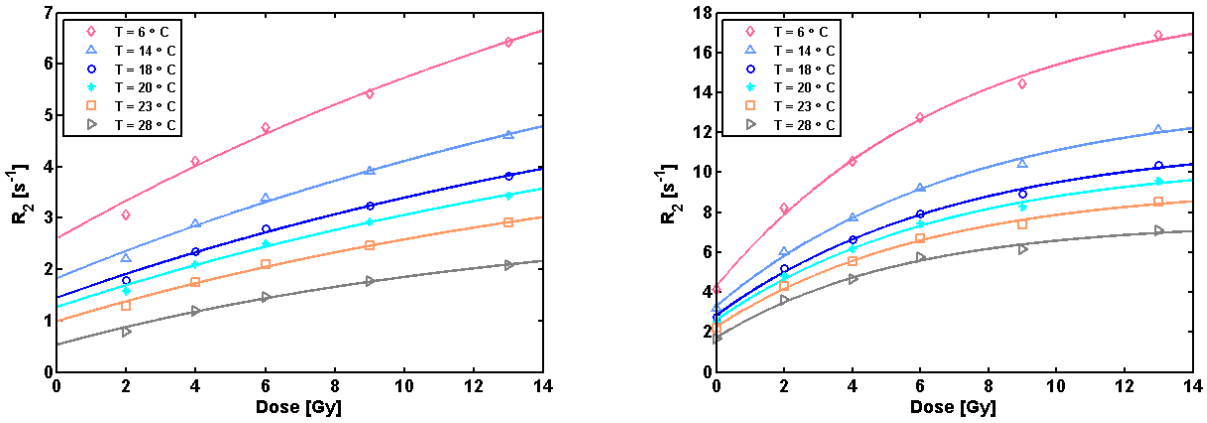
The absolute (U_D) and relative uncertainty ($U_{D,rel}$= U_D/D) attributed to a temperature change of ΔT = 1 °C are shown in figure 3 for different gels. In the lower dose region (up to 9 Gy), the dose uncertainty is decreased by adding glucose and sucrose. The lowest absolute uncertainty can be assigned to samples with 20% glucose and is around 0.09 and 0.52 Gy between delivered doses of 0 to 6 Gy, whereas the absolute dose uncertainty of PAGAT gel in this low dose range is between 0.43 and 0.83 Gy. U_D of the 20% glucose as well as of the 20% sucrose samples exceeds the uncertainty of PAGAT gel for doses above 9 Gy. PAGAT gel with 10% sucrose seems to have the lowest and most stable absolute dose uncertainty in the whole evaluated dose range. By adding 10% sucrose the dose uncertainty is reduced by between 0.18 Gy for a delivered dose of 2 Gy and 0.32 Gy for a delivered dose of 13 Gy compared to PAGAT gel.

No significant change in R_2-values was observed between 16 and 43 hours after irradiation. Therefore, observed changes in R_2 over time as a result of temporal instability were not considered in the analysis.

Another temperature dependence experiment with samples containing different gelatine concentrations (results not shown here) showed that the relative change in R_2 is considerably increased by adding a certain amount of gelatin. It is expected that the gelling agent plays a significant role in temperature sensitivity.

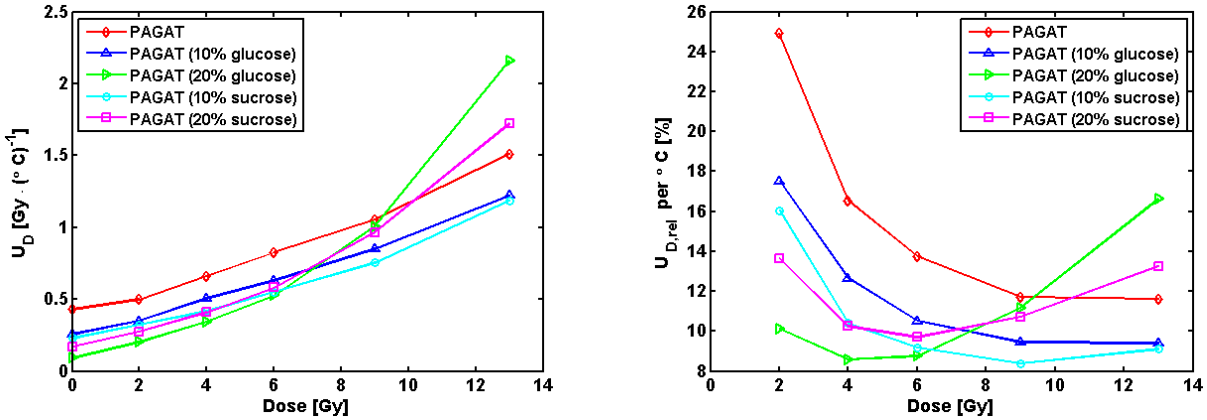
4. Conclusion

PAGAT gels with sucrose and glucose as additives showed a significant increase in dose response compared to conventional PAGAT gel. However, the temperature sensitivity during the read-out process is increased significantly. At lower doses, a small decrease in temperature related relative dose uncertainty is found. For higher doses, samples with a high sucrose or glucose concentration (20%) demonstrate an even higher dose uncertainty than PAGAT gel. In summary, although a higher dose sensitivity of PAGAT gels with saccharides additives was observed, adding glucose and sucrose does not correspond to a considerable improvement as compared to conventional PAGAT gel dosimeters.



(a) PAGAT gel (b) PAGAT gel with 20% glucose

Figure 2. Temperature dependence of R_2-dose response curves for (a) PAGAT gel and (b) PAGAT gel with 20% glucose.



(a) Absolute dose uncertainty (U_D) (b) Relative dose uncertainty ($U_{D,rel}$)

Figure 3. (a) Absolute and (b) relative dose uncertainty in determined dose caused by temperature variation around room temperature as a function of delivered dose. (Lines are drawn to guide the eye).

5. References

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