Initial experience of MAGIC gels, their reproducibility and their practical application in the clinic

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1. Introduction

MAGIC gels offer a practical solution to 3D dose verification for conventional radiotherapy as well as for intensity-modulated and stereotactic radiotherapy. This is largely owed to the simplicity with which they can be prepared. Unlike their more commonly used BANG gel equivalents, MAGIC gels are prepared under normoxic conditions. However, the question remains as to how suitable MAGIC gels are for use as a tool for performing valid dosimetry measurements in the clinic. To date, the reproducibility of the properties of MAGIC gels, particularly their response to radiation, remains unclear and literature on this topic is limited [1].

In this study we report on our initial experience with MAGIC gels as a dosimetric tool. In particular, we address the issue of the reproducibility of the gel’s response to radiation by measuring the spin-spin relaxation times of gels irradiated to known doses using magnetic resonance imaging (MRI) and a conventional multi-echo CPMG pulse sequence.

As a practical implementation of MAGIC gels into the clinic is required, the time to acquire images must be short. For this reason, the effect of the echo train length used in determining the spin-spin relaxation times was assessed as an initial investigation into whether alternative pulse sequences could be used to accurately measure the gels relaxation properties.

2. Materials and Methods

A 1.2 litre volume of MAGIC gel was prepared according to Fong’s formulation [2]. As an initial study of the reproducibility, thirty vials having a capacity of 39 ml were filled with the gel. The density of the gel was determined in order to ascertain its water equivalence. The gel density was found to be 0.991 g/cm³ compared to 1.000 g/cm³ for water (% difference = -1.0 %). The vials were stored in a fridge for approximately 30 hours after production.

Twenty five of the thirty vials were irradiated using a 6 MV photon beam to a range of known doses i.e. 5 vials x (2 Gy, 4 Gy, 6 Gy, 8 Gy, 10Gy). A parallel beam configuration was adopted to make these exposures. The remaining five vials were left unexposed.

To assess the reproducibility of the MAGIC gels response to radiation, the relaxation rate \( R_2 = 1/T_2 \), where \( T_2 \) is the spin-spin relaxation time) was measured on a Siemens 1.0 T magnetic resonance imaging scanner using a conventional Carr-Purcell-Meiboom-Gill multi-echo spin echo pulse sequence. Single slice images were obtained by positioning the slice locator through the centre of each vial and acquiring multiple images at several different echo times.
An adapted MATLAB [3] software routine [4] was used to reconstruct $R_2$ image maps from the multi-echo images. This was done by fitting the image signal amplitude versus echo time curves to a mono-exponential decay on a pixel by pixel basis. Curve fits were performed for fits to 14, 8 and 4 echoes. Values of $R_2$ for each vial were obtained by averaging the relaxation rate within a region of interest drawn on the $R_2$ images.

When the relaxation rate of MAGIC gels is plotted against dose, the response has been reported to be linear up to 30 Gy [2]. In this experiment, the response of the gel to radiation was determined by plotting the relaxation rate for each vial, determined for a given echo train length, against the radiation dose (Gy) to which it was exposed and fitting against a straight line from which the slope and the intercept were extracted. The slope related to the dose response of the gel and the intercept to its zero dose relaxation rate. It should be noted that, line fits were performed excluding all obviously erroneous data. Erroneous data arose as a result of poor positioning of the vials on the central axis during irradiation. Furthermore, it was observed that for this gel, the $R_2$ versus dose plots deviated from a straight line above 8 Gy. For this reason, linear fits were performed up to 8 Gy only.

3. Results

![Graphs showing $R_2$ as a function of dose](image)

**Figure 1.** Scatter plot showing $R_2$ as a function of dose in the range 0–8 Gy for each vial. $R_2$ values were calculated using MATLAB for 14, 8 and 4 echoes. The solid line corresponds to linear fits to the data.

The scatter plots in Figure 1 show how the relaxation rate of the gel varies linearly with dose up to 8 Gy for data acquired using 14, 8 and 4 echoes. The data points correspond to the average $R_2$ values for each vial irradiated in the dose range 0-8 Gy and the error bars to the standard deviation at each dose point. The solid line indicates the results of fitting the data to a straight line. The dose response of the gel was determined from the slope of this line. Results of linear fits for 14, 8 and 4 echoes are shown in Table 1, where $R_0$ is the zero dose relaxation rate, $R_2$/Gy is the gel dose response and $R^2$ is the coefficient of determination which indicates how closely the estimated line fits the actual data. A value close to 1 represents a good fit.
Table 1. Results of linear fits to relaxivity versus dose for 14, 8 and 4 echoes. SD is the standard deviation. The last row contains the average results for the three experiments. The values between brackets are the coefficients of variance.

|          | \(R_0\) [s\(^{-1}\)] | SD(\(R_0\)) [s\(^{-1}\)] | d\(R_2\)/dD [s\(^{-1}\).Gy\(^{-1}\)] | SD(\(R_2\)) [s\(^{-1}\).Gy\(^{-1}\)] | \(R^2\) |
|----------|------------------------|--------------------------|-------------------------------|---------------------------------|-------|
| 14 Echoes| 2.60                   | 0.15                     | 0.63                          | 0.03                            | 0.99  |
| 8 Echoes | 2.67                   | 0.18                     | 0.65                          | 0.04                            | 1.00  |
| 4 Echoes | 2.71                   | 0.37                     | 0.65                          | 0.04                            | 1.00  |
| Average  | 2.66                   | 0.06 (2.3 %)             | 0.64                          | 0.01 (1.6 %)                    | -     |

4. Conclusions

A preliminary investigation into the reproducibility of MAGIC gels has been undertaken. Reproducibility has been quantified at this stage using the coefficient of variance (= (standard deviation/ mean) * 100). The results shown in Figure 1 indicate that the unexposed gels show the greatest spread in relaxation rates, with a zero dose relaxation rate that is reproducible to within approximately 20 % of the mean. For irradiated gel, the reproducibility is within approximately 10 % of the mean. A larger spread in \(R_2\) at zero dose raises the question as to whether this is a consequence of the polymerisation process that occurs after gel manufacture.

From Figure 1 and Table 1, it can be seen that linear fits to \(R_2\) data determined for 14, 8 and 4 echoes show a gel dose response that is reproducible to within 2 % of the mean dose response while the actual uncertainty in the dose response itself, for each echo length is less than 7 %. It should be noted, that a full error analysis has not been completed. This work is in progress.

A multi-echo CPMG sequence is the gold standard for determining the T\(_2\) relaxation properties of polymers. However, not all clinical MRI scanners are equipped with this facility. As a preliminary study, this work shows that relaxation properties can be adequately assessed using a smaller number of echoes in the CPMG pulse sequence. In this way it may be possible to move to alternative pulse sequences such as Fast Spin Echo (FSE) with fewer echoes to image gels. Consequently, scanning times may be significantly reduced, making the use of gels in the clinic a more viable option for dosimetry purposes. For example, the duration of a typical 16 echo CPMG pulse sequence is approximately 30 minutes, while a 4 echo FSE having the same resolution has a duration of approximately 4 minutes. However, a drawback with using fewer echoes is that the statistical error will increase. Tests are currently under way to compare the relaxation properties of MAGIC gel using the conventional CPMG spin-echo pulse sequence and a FSE pulse sequence.

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