Relaxometry Changes in a Gel Dosimetry Phantom due to Continued RF Exposure

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Abstract. This study investigates the potential alteration in relaxation times in phantoms used for MRI gel-dosimetry due to their continued RF exposure from the MRI scanner used in the measurement process. The work quantifies these changes and establishes a tolerance for the image acquisition time as well as mapping the spatial distribution of these effects.

1. Introduction.
As MRI-gel dosimetry becomes increasingly used in the field of radiotherapy verification, the accuracy of the technique needs to be thoroughly established. There are many MRI-dependent factors that have the potential to introduce errors into the final dose map. Of these, the effect of temperature changes within the gel from the heating caused by RF absorption during the imaging procedure itself has been the least addressed. The dosimetric term for RF absorption is known as specific absorption rate (SAR) and has a quadratic dependence on field strength and flip angle and is dependent on other factors such as coil geometry. In order to map the dose deposited within the gel the dose-R₂ characteristic needs to be determined. This requires the acquisition of multiple echo imaging sequences in order to perform the necessary transverse relaxation time measurements, and requires the use of multiple RF pulses. Often repeat scanning in one flask is used to provide in situ calibration and/or for highly detailed plan verification. This leads to a RF intensive procedure that has the potential to introduce significant heating effects in the phantom. Changes in temperature will alter the background relaxation value and in turn affect the calibration efficacy leading to errors in the final dose calculation. As the diameter of the phantom becomes comparable with (half) the resonant wavelength of the system, the RF absorption becomes more efficient and temperature increases are likely to be an important consideration. At 3.0 Tesla the resonant wavelength is 26 cm. This study attempts to establish the tolerance for continued exposure to RF and map any spatial effects that exist during a typical scanning procedure.

2. Materials & Methods.
All imaging was performed on a 3.0 Tesla GE Signa scanner using a commercially available linear RF head coil. A two-litre flask of approximately 12 cm in diameter containing a MAGIC-type gel medium (Imagel Ltd, York, UK) and widely used for gel-dosimetry was imaged. This flask had previously been left overnight to reach ambient scan-room temperature of
approximately 18 °C. The imaging acquisition consisted of two dual-echo fast spin-echo (FSE) sequences with TEs equal to 30,105 & 60,180 ms and a TR of 4 s. This protocol has been used in previous dosimetry studies at our Centre. Axial images were acquired through the gel container with 5 mm slice thickness and 1 mm gap with an in-plane resolution of 0.9 mm. The gel temperature was measured using an MR-compatible fluoroscopic probe and extension (Lambda photometrics, UK). A needle and sheath was used to introduce the probe into the gel for ease and accuracy of positioning and then withdrawn outside the bore to leave the probe in place. Measurements were taken at the edges and centre of the phantom during the acquisitions. Data-logging software was used to continually record temperature. Scanner bore temperature was also recorded before and after scanning. A total of seven repeat acquisitions (two signal averages each) were successively collected over a total period of 72 minutes. R$_2$ was estimated at the end of each sequence in small regions-of-interest using a semi-weighted log fit to the data. In addition, pixel-by-pixel maps of $\Delta$R$_2$ were also produced by subtracting each subsequent repeat measurement from the first acquisition using in-house developed software (Dosemap2003, MATLAB) in order to visually monitor heating changes.

3. Results

Bore temperature remained constant throughout the examination. Within the gel itself, temperature changes of up to 1.4 °C were observed at the edges of the flask and a concomitant decrease of R$_2$ by 4.0 %. Figure 1 plots the temperature distribution (blue) during the course of scanning together with changes in R$_2$ measurements (pink) in a region at the edge of the flask. In contrast, the centre of the flask demonstrated smaller changes with a temperature increase and R$_2$ decrease of 0.3 °C and 2.6 % respectively.

![Figure 1](image-url) Figure 1: (above) A plot of temperature changes (in blue) and R$_2$ values (in pink) in a region at the edge of the gel flask during continued RF exposure of up to 72 minutes.

Figure 2 shows maps of $\Delta$R$_2$ calculated by subtracting each subsequent acquisition from the first R$_2$ map. These maps (left to right and top to bottom) demonstrate increasing values of $\Delta$R$_2$ (i.e. a continuing decrease in R$_2$) from which the increase in temperature can be inferred. There is a clear trend for the heating to dominate at the periphery of the flask with a much smaller and more gradual increase towards the centre. The increased temperature at the edges also appears asymmetrical.
Using previous data from our earlier calibration studies, the maximum temperature increases observed here would equate to between a 0.8 % and 5.4 % error in the estimated dose. This is clearly dependent on the characteristic (sensitivity) of the gel material.

Figure 2: (above) Pixel-by-pixel maps of $\Delta R_2$ every 12 minutes (a to e) show the evolution of the relaxation rate decrease due to temperature changes ($T_2$-weighted image of gel phantom also shown in first map).

4. Discussion.
This study establishes that temperature is unlikely to cause a significant component of the final dose error if scanning is restricted to less than 36 min based on previous data from our gel dosimetry studies. However, scanning beyond this time creates a significant heating effect at the edge of the dosimeter and alters the relaxation time of the gel in this region of sufficient degree that this could limit the absolute accuracy of the technique. It is of note that this temperature distribution is not uniform and will be dependent on the flask size, and be specific to the imaging sequence and RF component of the system in use. The maps of $\Delta R_2$ are an effective way of mapping these RF heating changes and may be useful for investigating other sequences and systems in a similar way to establish the tolerance of these effects.