Optimization of the T2 parametric image map calculation in MRI polymer gel dosimetry

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1. Introduction
In polymer gel dosimetry, Magnetic Resonance Imaging (MRI) provides the spin-spin relaxation rate $R_2=1/T_2$ image data, which in turn is correlated with the absorbed dose in the irradiated gel dosimeter. The $R_2$ vs. dose correlation is based on a calibration curve, which is derived from calibration samples irradiated to known doses. A number of factors influence the uncertainty of dose determination including the gel preparation procedure, the choice of MRI pulse sequence, and the mathematical method applied to measure the physical quantity $R_2$ [1,2]. Optimized methodology is therefore required to minimize the error in determining dose, and therefore obtain optimal results.

The aim of this work is to compare two different mathematical models in determining $R_2$, in terms of precision namely: i) the routinely applied conventional linear regression fitting model, and ii) a new weighted fitting model, which is based on the random noise figure applied for each signal of the T2 decay curve. To investigate the precision of the above models over a wide range of T2 values we have manufactured VIPAR gels with varying gelatine content and irradiated them to known doses.

2. Materials and methods

2.1. Gel preparation and Irradiation
The polymer N-vinylpirrolidone argon (VIPAR) gels were prepared according to the procedure described by Pappas et al [3]. Three gel batches were manufactured, each having the same monomer (N-vinylpirrolidone, 4%w/w) and cross-linker (N,N’-methylene-bis-acrylamide, 4%w/w) concentrations but different gelatine content. In particular, gelatine concentrations were 5%w/w, 6%w/w, and 7%w/w for the three batches, respectively. After the fabrication procedure, each gel was filled in a plexi-glass container with a volume of about 1 litre and stored at room temperature.

Irradiations were performed 24 h after the fabrication of the gels, using a 6 MV x-ray linear accelerator (Primus LINAC, Siemens), calibrated to deliver 0.01 Gy per monitor unit, in water, at the depth of maximum dose ($d = 1.5$ cm), with SSD 100 cm, a field size of 10 cm x 10 cm and a dose rate of 3 Gy min$^{-1}$. Prior to irradiation each gel container was placed in a solid water phantom to provide adequate build-up and scattering conditions. Each gel container was irradiated with three (3 cm x 3 cm) beams, placed 2.5 cm apart from each other. Delivered doses, at the depth of maximum dose, were 10, 30, and 50 Gy, respectively.
2.2. MR imaging and T2 parametric image maps calculation

The VIPAR gel containers were scanned with a 1.5 T whole body superconducting imager (Sonata/Vision Siemens). All MR scans were performed 24 h after irradiation. A standard quadrature RF body coil was used for signal excitation and a two channel phased array head coil for signal detection. MR scanning conformed of a 2D multi-slice-Multi-Echo (32 echoes) Spin Echo (MSMESE) PHAPS train sequence (TR / TE1 / TE32 / FA, 8500 ms / 25 ms / 800 ms / 180°). The applied MR sequence provided 5 mm slice thickness images, with 1 mm in-plane spatial resolution. T2 calculations were performed on a voxel by voxel basis by applying both conventional and weighted linear regression analysis on the voxel signal intensities. The signal intensities were measured in each of the successive temporal images obtained by the MR sequence. Numeric fitting and all relevant quantitative MR image analysis for the constructin of the T2 parametric maps were performed using an in-house developed image processing extension to the EvoRad RIS/PACS system designed for this purpose by two of the authors (T.G.M, K.K).

![Figure 1](image1.png)

**Figure 1.** a) A photograph of the irradiated gel phantom, b) A T2 parametric image map of the irradiated gel phantom.

![Figure 2](image2.png)

**Figure 2.** R2 (s⁻¹) vs. Dose (Gy) for all VIPAR gels used in this study (5%, 6%, 7% w/w gelatine) and with two different fitting models (weighted and conventional linear regression)
3. Results and Discussion

The gel calibration procedure, followed in this study, provided a linear R2 vs. dose response curve for all gel batches. The use of different fitting models in the T2 calculation (conventional linear regression, weighted) did not affect the linearity of the calibration curve (Figure 2). Theoretically, alterations of the gelatine concentration in the VIPAR gels were not expected to affect their R2-dose sensitivity [4]. Using the weighted fitting model, the R2-dose sensitivity figured 0.05sec\(^{-1}\)Gy\(^{-1}\) in all three gel batches (5%, 6%, 7% w/w gelatine). However, using the conventional linear regression fitting model, small variations in the gels sensitivity values were observed.

In order to compare the two different T2 measurement techniques in terms of precision, several MR scans of all gel batches were performed maintaining the same MR scanning parameters for each

**Figure 3.** The precision (CV) of the two different linear regression fitting models (weighted vs. conventional linear regression) plotted against the mean T2 values for VIPAR gels with gelatine concentration a) 5% w/w, b) 6% w/w, c) 7% w/w.
measurement. After each MR scanning procedure a T2 parametric map was calculated using both fitting models. The results of this investigation are illustrated in Figure 3. A higher precision of the calculated T2, expressed as a coefficient of variation (CV) [2], is clearly observed using the weighted fitting model instead of the conventional linear regression one. Furthermore, it is revealed that the optimization of the T2 calculation precision is significantly stronger in lower T2 measured values. The Bland & Altman plot (Bland & Altman, 1986 and 1999) was used as a statistical method to compare the two different R2 measurement techniques (Figure 4). In this graphical method the differences between the values measured by two techniques are plotted against their averages. This statistical test confirms a correlation of the R2 value with its variation when calculated by the two different fitting methods.

4. Conclusion
The comparison of the conventional linear regression fitting model in T2 parametric image map calculation with the newly designed weighted fitting model revealed a significant advantage of the latter in terms of precision. Further optimization of the T2 parametric image map calculation may be achieved by applying this weighted fitting method to polymer gels dosimeters with increased gelatine content.

5. References
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Figure 4. The Bland & Altman plot comparing the two different R2 measurement techniques (Weighted vs. Conventional linear regression fitting model)