Dosimetric performances of optically detected Fricke gel

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1. Introduction
Gel dosimetry has elicited a large interest since its first appearance as technique about unique to perform three dimensional dose mapping for quality assurance of treatment plannings in radiotherapy. Two main gel systems, polymer gels and Fricke-gels, are presently under investigation worldwide for their possible use as 3D dosimeters [1]. Both systems may be monitored with Magnetic Resonance or with optical techniques. A large effort is presently devoted to the development of optical techniques for their low cost and easy use of relative instrumentation. We devoted our attention to Fricke-gels because they have the advantage of a simpler preparation. They are soft-tissue equivalent over a very large photon energy range and Fricke-gel phantoms can be prepared containing heterogeneities mimicking other tissues. The main drawback of the system, that is ion diffusion after irradiation can be overcome by the use of optical techniques, particularly as that utilized by us based on a CCD for detection, due to very quick acquisitions of 2D projections. Addition of the dye Xylenol Orange (XO) complexing the oxidized metal ions in Fricke-gel systems provides the additional opportunity to measure the dosimeter absorbance in the range of visible light, enhancing both sensitivity and specificity of the optical analysis. The presence of XO in the gel further reduces ferric ion diffusion. Two series of experiments are presented here. The first one is aimed at examining dosimetric performances of the gel and is relative to uniform dose distributions; the second one is aimed at comparing dose distributions obtained with the gel with those obtained with point dosimeters.

2. Materials and Methods
We used a CCD based device designed for reading Radiochromic films, modified to meet the optical properties of the dosimeter. A description of the device and of its characteristics can be found in reference [2].

The Fricke-gel used in this work is the Fricke-agarose gel that includes 0.25mM Xylenol Orange. We have used this concentration of Xylenol Orange because it allowed a sufficient control of Ferric ions diffusion while maintaining good sensitivity: the diffusion coefficient was 1.14 mm²/h [3]. Furthermore, we added sucrose to make the sample more homogeneous.

3. Results and Discussion
Two-dimension projections of the Fricke-gel, uniformly irradiated with a ¹³⁷Cs source in a 10 x 10 x 45 mm cuvette, were acquired. A region of interest of 30 x 140 pixels corresponding to 5.2 x 24.4 mm² was considered and the difference ΔOD between the optical density of the irradiated sample OD₉₉ and optical density of same sample before irradiation ODₐ, set in the same position with respect to the light source, was calculated:
\[ \Delta OD = OD_{irr} - OD_c = \log \left( \frac{I_0}{[I_T]_{irr}} \right) - \log \left( \frac{I_0}{[I_T]_c} \right) = \log \left( \frac{[I_T]_c}{[I_T]_{irr}} \right) \]

where \( I_0 \) is the intensity of incident light, \( I_T \) that of transmitted light; \([I_T]_c\) and \([I_T]_{irr}\) are the intensity of transmitted light of control and irradiated samples.

Figure 1a shows a representative experiment of the dose-response curve where measurements are fitted with an exponential function \( \Delta OD = a(1-\exp(-bd)) \), where \( d \) is the absorbed dose and \( a \) and \( b \) are fitting parameters.

The linear approximation \( \Delta OD = c d \), with dose \( d \) and \( c \) fitting parameter, is valid in the dose range 0 - 10 Gy. In this range, \( \chi^2 \) is lower than 10^{-4} for both linear and exponential fittings. Figure 1b shows the goodness of the fit together with the value of \( c \) for a representative experiment in a low dose range. Beside the goodness of the fit of the calibration curve, the standard deviation of pixel values in the region of interest influences the random uncertainty. In the dose range 0 - 10 Gy and for a spatial resolution of 1 x 1 mm², addition of sucrose lowers the uncertainty of the measured \( \Delta OD \) below 1% (1\sigma). The minimal difference between two absorbed doses that allows them to be distinguished with a 95% level of confidence ranges from 0.02 Gy (0.5 Gy) to 0.2 (10 Gy).

We have then compared dose distributions of the Fricke-gel with dose measurements obtained with other dosimetric systems. To create a non uniform dose distribution in a \( ^{60}\)Co gamma cell, we used an home-built lead phantom, in which a cylindrical vial containing Fricke-gel was inserted. We irradiated the sample with a dose of 10 Gy creating a dose distribution along the main axis of the cylindrical sample. After removing the gel sample, three TLD and two alanine dosimeters were placed in specific points of the lead phantom and dose values determined. A linear calibration for the gel data has been used by using the dose value read by the TLD in the first position (dose value 0.67 ± 0.01 Gy).

Figure 2a shows the optical density difference \( \Delta OD \) of the Fricke-gel, converted in dose values, along the main axis of the cylindrical sample measured with a resolution of 1 mm². Dose values obtained with TLD and alanine are reported in Figure 2b together with those obtained from the gel. In this case, the dose value obtained from the gel was calculated on a region that was encompassing the same region of TLD or alanine dosimeters. The dose distribution obtained in the gel showed very good agreement with dose values measured with point dosimeters.

**Gel: uniform irradiation**

![Figure 1](image)

**Figure 1.** Panel a: \( \Delta OD \) of Fricke gel irradiated in the range (0.5-40) Gy, fitted with an exponential curve. Panel b: \( \Delta OD \) of Fricke gel irradiated in the range (0.5-3.7) Gy, fitted with a linear curve.
4. Conclusions
The dosimetric performances of the Fricke gel here examined indicate that this system is very promising for mapping 3D dose distributions with a high spatial resolution.

Figure 2. Panel a: Dose distribution along the main axis of a cylindrical gel sample inserted into a lead phantom shielding the lower part. Panel b: Comparison of dose values measured with gel (open triangles), TLD (solid squares) and alanine (solid diamonds). The solid circle indicates the dose value used for gel calibration.

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