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Characterization of PVA-GTA Fricke gels dosimeters using MRI and optical techniques in X-rays external radiation therapy

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Summary. — In this work, recent results about the dependence of the response of poly(vinyl-alcohol)-glutaraldehyde Fricke gel dosimeters on the irradiation and holding temperatures are reported. The investigations were carried out by two complementary techniques commonly used in gel dosimetry, namely spectrophotometry and MRI. No significant dependence of the dosimeters sensitivity on the irradiation temperature in the range 20 °C–35 °C was observed. On the contrary, the holding temperature effects resulted to be not negligible. This work, based on literature results, highlights the limits and the capability of these dosimeters in the 3D dose mapping for clinical practice applications.

1. – Introduction

Fricke gel (FG) dosimeters have been extensively studied for their dosimetric potential properties due both to the use of solutions of ferrous sulfate (in which the radiation-induced production of ferric ions from ferrous ions depends on the irradiation dose) and to the rigidity of the gel matrix [1], which hinders the ferric ions from freely diffusing in the matrix. These features represent a clear advantage with respect to the use of aqueous solutions, which do not preserve any spatial information on the dose-dependent changes of the local magnetic properties related to the local ferric ions concentration. Thanks to these features, Fricke gel dosimeters can be considered as ideal candidates for performing 3D reconstruction of dose distribution. A number of experiments on FG aimed at optimizing their composition both to increase the dose sensitivity and/or the local stability of the radiation-produced ferric ions. Their applications for clinical dosimetry are reported in the literature [2, 3]. Several studies suggest hydrogel systems based on the use of poly(vinyl-alcohol) (PVA) cross-linked by adding glutaraldehyde (GTA) as a matrix for FG [4-10].

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PVA-GTA-FG dosimeters proved to be nearly water-equivalent and characterized by a linear dose-response, which is independent of the energy and dose rate, in the typical intervals of interest for radiation therapy. The dependence of their dosimetric properties on the irradiation temperature and on temperature changes occurring between the irradiation and readout phases was also investigated [11]. Due to the increased interest toward PVA-GTA-FG dosimeters for clinical practice applications, some of the most promising results obtained by our research group on their dosimetric properties, will be briefly discussed in this work.

2. – Materials and methods

The details on the preparation, irradiation and investigation of the PVA-GTA-FG dosimeters are reported in [10-13]

2˙1. *Dose-response measurements.* – The PVA-GTA Fricke gel dosimeters were uniformly irradiated with a linear accelerator Varian Clinac-2100. The PVA-GTA Fricke gel dosimeters were exposed to different dose values, with 6 MV X-rays, at the controlled temperatures of 20°, 25°, 30° and 35°C. The samples were left to thermalize in water for at least 10 minutes before the irradiation. The thermalization was monitored by measuring the temperature inside one reference gel sample. The samples were irradiated up to 20 Gy. For each dose value, three samples were irradiated. Un-irradiated FG dosimeters were subjected to different thermal-stress events by using the thermalized water phantom. Starting from refrigerator-temperature, the samples were heated up to temperatures of 11 °C, 20 °C and 30 °C for 120 min.

An UV-Vis spectrophotometer was used for Optical Absorbance (OA) measurements of the irradiated samples in the wavelength range 360–720 nm. OA spectra were acquired using ultrapure water as reference. According to the indications of previous studies [10], the OA values at 520, 555 and 585 nm were used to reconstruct the dose-response curves. For quantitative analyzes, the integral of OA variation Σ(OA), *i.e.*, sum of OA values between 480 and 620 nm was chosen as dosimetric parameter [11]. Complementarily, T_1 weighted magnetic resonance images were acquired using a 1.5 T clinical Magnetic Resonance Scanner equipped with an eight channel head coil and a *Turbo Inversion Recovery Sequence* optimized for brain. The images were acquired after 30 min thermalization of samples at room temperature [11].

3. – Results

3˙1. *Optical absorbance spectra.* – Typical optical absorbance spectra of Fricke-XO gel dosimeters irradiated at 25 °C with different doses are shown in fig. 1(a).

The optical absorbance spectra in fig. 1(a) showed the broad absorption band above 500 nm. This band is composed at least of two peaks at 520 nm and 585 nm due to the different chelation mode of XO with ferric ions, showing an isosbestic point at 555 nm in the OA spectra [10]. Increasing the radiation dose, the intensity of the absorbance signal increased accordingly, with a consequent reduction of the absorption band at 430 nm, due to the XO molecules not bound with ferrous ions. The shapes of the optical absorbance spectra of PVA-GTA-FG dosimeters were very similar to those of FG dosimeters prepared with natural gelation matrices [2]. In order to evaluate the effect of the radiation on the optical absorbance, the dose response curves of the dosimeters irradiated at various doses at several indicative wavelengths are plotted in fig. 1(b). Considering the fact that the

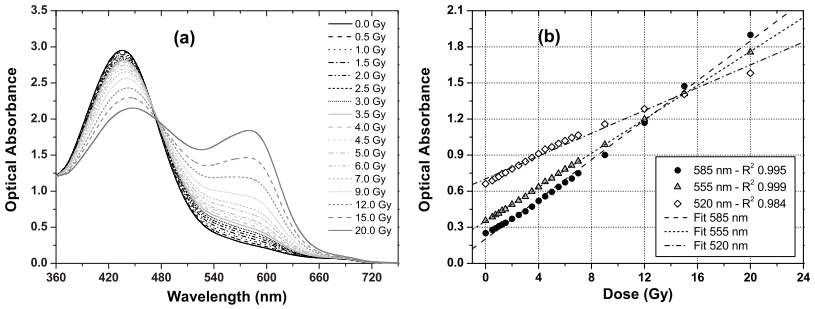

Fig. 1. – (a) OA spectra of PVA-GTA-FG dosimeters irradiated at 25 °C to different doses up to 20 Gy. Ultrapure water was used as reference. (b) OA at 520, 555 and 585 nm, respectively of PVA-GTA Fricke gels irradiated at various doses in the interval 0–20 Gy using 6 MV photon beams. Each point is the mean of measurements on at least three samples. The dashed lines are the linear fit to the experimental data.

signal of an ideal dosimeter should be linearly proportional to the absorbed dose over the entire dose range of interest, it is possible to deduce from fig. 1(b) that a linear response curve is achievable only at the isosbestic point with R^2 index approximatively equal to 1 ($\lambda = 555$ nm). On the other hand, the wavelength of 585 nm, where the absorbance reaches the maximum value (experimental situation normally proposed in the literature), the dosimeters lose the linearity below 5.0 Gy preventing their uses at low doses. Similar considerations can be made for the absorption peak at 520 nm.

3˙2. *Influence of the irradiation temperature on the dose-response curve.* – Regarding dosimetric response on the irradiation temperature, in Gallo *et al.* 2020 [11] the focus is on the OA and the nuclear relaxation rate ($R_1 = 1/T_1$) of the gel samples irradiated at different temperatures. Here, for completeness, the signal trends from MRI images acquired with $T_I = 600$ ms of the samples irradiated at different temperatures ($T = 20\,^{\circ}$C, $25\,^{\circ}$C, $30\,^{\circ}$C and $35\,^{\circ}$C) are shown in fig. 2. Each value of intensity in fig. 2 is the average of three different samples. Error bars correspond to one standard deviation. It is evident an increase of the MRI signal intensity with increasing the radiation dose. No significant variation of this trend with changing the irradiation temperature was observed. Indeed, for each dose, the MRI signals of samples irradiates at different temperatures were comparable, within the experimental errors.

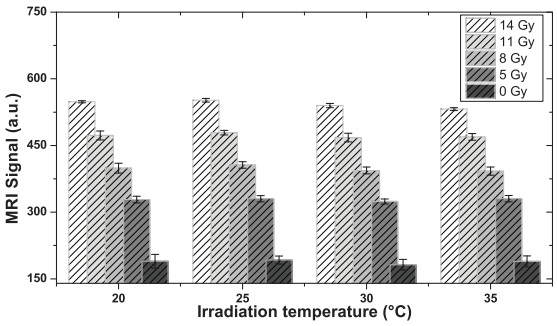

Fig. 2. – Comparison of the MRI signal intensity at $T_I = 600$ ms of PVA-GTA-FG irradiated at different temperatures.

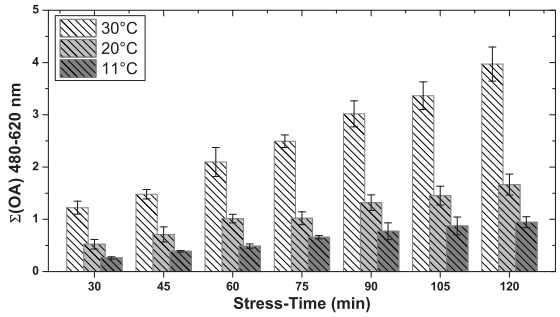

Fig. 3. – ΣOA of un-irradiated FGs *vs.* stress-time for the different stress-temperatures.

3˙3. *Thermal-stress effect.* – The influence of thermal-stress events on un-irradiated FG dosimeters at 11 °C, 20 °C and 30 °C, as tested in Gallo *et al.* 2020 [11], has been reported here to study the auto-oxidation process over the time.

The values of Σ(OA), reported in fig. 3, were calculated from the OA spectra acquired at different times of thermal-stress for each temperature. In all the cases presented, the obtained values increase with the stress-time and depend on the thermal-stress temperature, the higher the thermal stress temperature, the greater the integral optical values. In addition, it can be deduced that a thermal-stress condition before the use of the FG dosimeters may induce an overestimation of Σ(OA) and consequently of the reconstructed dose, caused by an additional oxidation process inside the gel that does not depend on irradiation.

4. – Conclusions

Recent results about the dependence of the response of PVA-GTA-FGs on the irradiation and holding temperatures were summarized and discussed. These findings contribute to hightlight the potentialities and limits of these systems for 3D dose mapping in clinical practice applications.

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