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STUDY OF THE STABILITY, REPRODUCIBILITY AND DOSE RATE DEPENDENCE OF THE FRICKE GEL DOSIMETER DEVELOPED AT IPEN

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ABSTRACT

Among the gel dosimetry methods studied by many researchers the Fricke gel dosimeter is very useful in the treatment planning of tumors by ionizing radiation. Aiming to calibrate and improve the performance of the Fricke gel solution developed at IPEN, in this work some dosimetric properties of the Fricke gel solution prepared using 240 Bloom gelatin were studied. The stability of non-irradiated and irradiated solutions with gamma radiation of the ^{60}Co (10 Gy) prepared with different concentrations (1% and 5%) of 240 Bloom edible bovine gelatin maintained under three different storage conditions: (1) under refrigeration and light protected, (2) room temperature and ambient light and (3) room temperature and light protected; the reproducibility of different solution batches and the dose rate dependence of the optical response (irradiated with doses of 10 and 30 Gy) were evaluated using the spectrophotometric technique. The Fricke gel solutions that were maintained in the first storage condition (under refrigeration and light protected) presented better stability than the solutions maintained under other conditions. This behavior was observed to solutions prepared with the two studied gelatin concentrations (1% and 5%) and non-irradiated and irradiated samples. The reproducibility of different Fricke gel solution batches prepared with 5% of gelatin is better than ± 10%. The dose rate dependence of the spectrophotometric response for dose rates between 3.29 and 0.329 kGy/h for absorbed doses of 10 and 30 Gy was ± 10% and ± 3% respectively.

1. INTRODUCTION

Gel dosimetry methods have been studied by many researchers and different materials have been proposed for such application. Among them the Fricke gel dosimeter is very useful in the treatment planning of tumors by ionizing radiation, whose dosimetry is based on the oxidation of ferrous ion (Fe^{2+}) to ferric ion (Fe^{3+}) radiation induced [1]. The Fricke gel dosimetric system presents some advantages compared to other gel dosimetry systems. For example the gelatinous solutions are easily prepared and the 3D dose distribution can be obtained using magnetic resonance image technique immediately after irradiation [2].

The purpose of this work was to study the stability, reproducibility and dose rate dependence of the Fricke gel dosimeter developed at IPEN prepared using 240 Bloom gelatin to be used to prepare organ phantoms to obtain 3D dose distribution using MRI technique.

2. MATERIALS AND METHODS

The experimental procedures for solutions preparation were performed using the Chemical Dosimetry Laboratory of the Radiation Metrology Centre (CMR) of Instituto de Pesquisas Energéticas e Nucleares (IPEN / CNEN - SP). The Fricke gel solutions studied were prepared using 240 Bloom edible bovine gelatin, 50 mM of sulfuric acid (H_2SO_4), 1 mM of ferrous ammonium sulfate or Mohr salt [$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$], 1 mM of sodium chloride (NaCl) and 0,1 mM of xylenol orange ($C_{31}H_{28}N_2Na_4O_{13}S$) – iron ions indicator; all these materials are reagents of analytical grade [1].

2.1. Preparation

Fricke gel solutions were prepared [1] with concentrations of 1% and 5% of 240 Bloom gelatin [3]. The obtained solutions of each batch were always conditioned in three acrylic cuvets (optical path length of 10 mm) for each analyzed condition (in order to use the arithmetical mean of the measurements). For spectrophotometric response stability determination the Fricke gel solutions were maintained under three different storage conditions: (1) under refrigeration and light protected, (2) room temperature and ambient light and (3) room temperature and light protected. The non-irradiated cuvets filled with Fricke gel solutions were maintained under these three storage conditions. To obtain the different solution batches reproducibility six batches of dosimetric solutions were prepared and for dose rate response dependence determination the dosimetric solution was prepared with only one gelatin concentration (5%). Spectrophotometric measurements were performed immediately after preparation of all solutions. Subsequently the cuvets were maintained under refrigeration (~ 5º C) and light protected during 12 h before irradiation.

2.2. Irradiation

Thirty minutes before irradiation the solutions were removed from the refrigerator and maintained at room temperature. The dosimeters were irradiated in the same cuvete using a ^{60}Co gamma radiation source (Gammacell 220) at Radiation Technology Center (CTR, IPEN / CNEN - SP) with absorbed dose of 10 Gy for spectrophotometric response stability evaluation (dose rates of 3.48 kGy/h for conditions 2 and 3 and 3.44 kGy/h, for condition 1) and with doses of 10 and 30 Gy for dose rate dependence response. The different dose rates were obtained using the following conditions: without attenuation (3.29 kGy/h) and with 50% attenuation (1.645 kGy/h), 70% attenuation (0.987 kGy/h) and 90% attenuation (0.329 kGy/h).

All irradiations were performed in free air and at electronic equilibrium conditions. The dosimetric solutions prepared in order to determine the batches reproducibility were not irradiated.

2.3. Evaluation

The evaluation technique used in this work was the spectrophotometry. The used equipment was the spectrophotometer SHIMADZU model UV-2101PC. All spectrophotometric measurements were obtained in the optical range between 190 nm to 900 nm. To study the spectrophotometric response stability the measurements were performed immediately after the preparation and after irradiation of the dosimetric solutions. The dosimetric solutions

were maintained under the three storage conditions previously proposed and analyzed according to the following schedule: each 30 minutes during the irradiation day; daily and weekly during 30 days. The results of reproducibility of the six batches of dosimetric solution and evaluation of the dose rate dependence response for each proposed condition (with and without attenuation) were also analyzed.

3. RESULTS AND DISCUSSIONS

All absorbance values presented in this work were evaluated in the wavelength of the 585 nm [2].

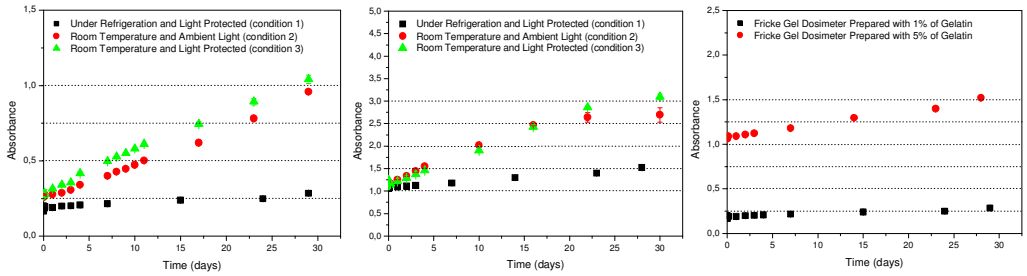
3.1. Stability of the Fricke Gel Dosimeter

When maintained under refrigeration (~ 5° C) the Fricke gel solutions prepared with different gelatin concentrations (1% and 5%) present solid form. Under room temperature solutions prepared with 5% of gelatin presented better performance, however both type of gels liquefies after ± 1.5 h at room temperature.

3.1.1 Non-irradiated solutions

The spectrophotometric response of the Fricke gel solutions prepared with 1% of gelatin presented more stability for condition 1 than for conditions 2 and 3, however in all cases it was observed intensification of the absorbance values along the time. Observing the solution color variation [3], significant intensification of the absorbance values 30%, 73% and 74% for the three conditions respectively occurred during the analysis period in solutions containing 1% gelatin (Fig. 1A) and 29%, 58% and 60% in solutions prepared with 5% of gelatin (Fig. 1B). These results are less evident under condition 1. After 30 days it was observed for conditions 2 and 3 the formation of fungus (Fig. 1B).

Fig. 1C presents the behavior of the non-irradiated Fricke gel solutions prepared with 1% and 5% of gelatin, referring to the condition 1 (under refrigeration and light protected). It can be seeing that the dosimetric solution prepared with 5% of gelatin presents higher absorbance values and that they are intensified throughout the time.

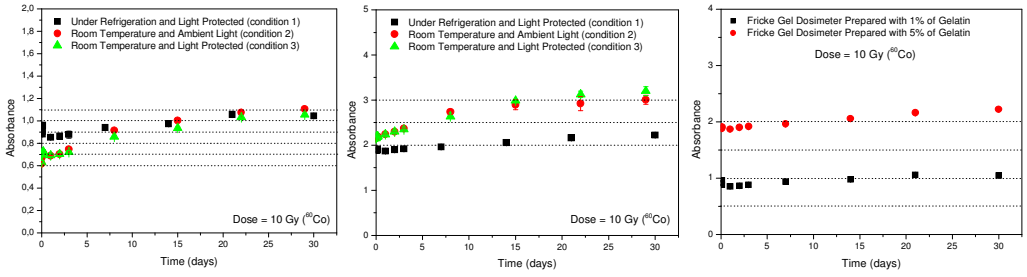


(A) (B) (C)

Figure 1. Stability of the non-irradiated Fricke gel solutions prepared with 1% (A) and 5% (B) of gelatin maintained under three different storage conditions. Non-irradiated Fricke gel dosimeters prepared with 1% and 5% of gelatin maintained under condition 1 (C).

3.1.2 Irradiated solutions

According to the results presented in Fig. 2A the irradiated Fricke gel solution prepared with 1% of gelatin presented intensification of the absorbance values of 12%, 44% and 40% with storage time respectively in the three analyzed conditions. However, the irradiated dosimetric solution (1% of gelatin) that was maintained under refrigeration and light protected presented more stable response. Under conditions 2 and 3 irradiated Fricke gel solution prepared with 5% of gelatin melted and presented formation of fungus after 15 days of analysis. It can be observed in Fig. 2B that the irradiated solution presented intensification in the absorbance values of 14%, 29% and 33% after the storage time respectively to the three analysis conditions, being the most stable the response of the solution that was maintained cooled and light protected. Fig. 2C presents the behavior of the irradiated Fricke gel solutions (10 Gy) prepared with 1% and 5% of gelatin referring to condition 1. It is observed that the irradiated solution prepared with 5% of gelatin also presents higher absorbance values than the irradiated solution prepared with 1% of gelatin.



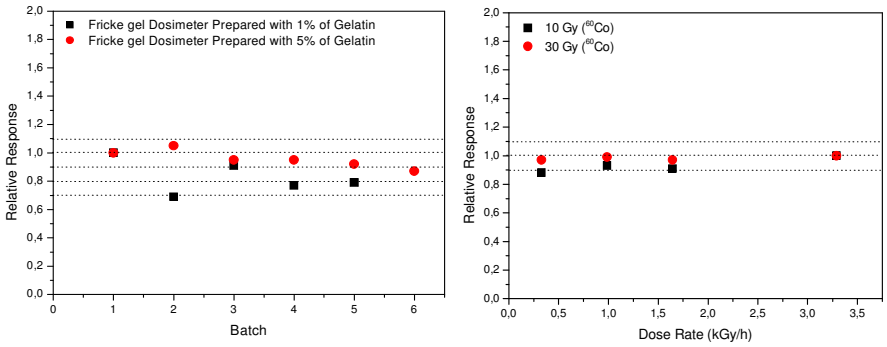
(A) (B) (C)

Figure 2. Response stability of irradiated Fricke gel dosimeters prepared with 1% (A) and 5% (B) of gelatin maintained under three different storage conditions. Irradiated Fricke gel dosimeters prepared with 1% and 5% of gelatin under the condition 1 (C).

3.2. Reproducibility and Dose Rate Dependence of the Fricke Gel Dosimeter

Fig. 3A presents the reproducibility of non-irradiated Fricke gel solutions prepared with different gelatin concentrations (1% and 5%). The reproducibility of the Fricke gel solution prepared with 5% of gelatin is better than ± 10% and the reproducibility of the solution prepared with 1% of the gelatin can be improved by using other qualities of gelatin for example. The variation of the Fricke gel dosimeter response between different batches can be related to the external factors such as the temperature of the water used to prepare the gelatinous solution.

Fig. 3B presents the absorbance values obtained for dose rate of 3.29 kGy/h, without attenuation, and 1.645, 0.987 and 0.329 kGy/h (50%, 70% and 90% attenuation respectively) for irradiations with doses of 10 and 30 Gy. According to the obtained results the dose rate dependence of the spectrophotometric response for dose rates between 3.29 and 0.329 kGy/h and absorbed dose of 10 Gy was ± 10 % and for absorbed dose of 30 Gy ± 3 %.



(A) (B)

Figure 3. Reproducibility of spectrophotometric response of Fricke gel solutions for different batches (A). Dose rate dependence response of irradiated Fricke gel solutions prepared with 5% of gelatin (B).

4. CONCLUSIONS

The Fricke gel solutions prepared with 5% of 240 Bloom edible bovine gelatin presented better consistency and sensitivity when maintained under refrigeration (~ 5º C) and light protected and reproducibility better than ± 10%. The dose rate dependence of the spectrophotometric response for dose rates between 3.29 and 0.329 kGy/h and absorbed dose of 10 Gy was ± 10% and ± 3% for absorbed dose of 30 Gy. These results can be improved changing the concentrations of the mixture compounds and gelatin concentration.
Although the 240 Bloom gelatin isn't the most indicated to Fricke gel solutions preparation, this results are interesting when phantoms of different organs must be prepared with dosimetric solution, in this case big solution volumes are needed and this type of gelatin is less expensive and easily found in local market.

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