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INFLUENCE OF GELATINE CONCENTRATION AND QUALITY IN THE SPECTROPHOTOMETRIC RESPONSE OF FRICKE GEL SOLUTION

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ABSTRACT

The Fricke gel dosimetry is a very attractive technique for radiation treatment plannings because it allows the spatial dose distribution verification by using of three-dimensional (3D) geometry phantoms. To obtain the Fricke gel dosimeter is commonly used 300 Bloom gelatine, that is imported and therefore expensive. In this work a comparative study between gel solutions prepared with 270 Bloom gelatine, of national quality, and 300 Bloom gelatine, imported, was made. The non-irradiated and irradiated (^{60}Co gamma radiation) dosimetric solutions prepared with the different gelatine qualities presented similar behavior concerning color change, consistence, hydrogen potential and spectrophotometric response stability. The results obtained in this study complement the previous studies about the performance of Fricke gel solutions prepared using 270 Bloom gelatine and they indicate that the solution can be used as radiation dosimeter for quality control and 3D dose distribution evaluation in radiotherapy and radiosurgery procedures in Brazil.

1. INTRODUCTION

To obtain satisfactory results in the malignant tumours radiation treatments without compromising of the adjacent healthy tissues it is necessary carry out a planning for each treatment, to define with precision the volume to be irradiated, the dose to be administered, the radiation quality and the equipment to be used [1,2]. The gel dosimetry is a very attractive technique for radiation treatment plannings. It allows the spatial dose distribution verification in complex clinical situations (Intensity Modulated Radiotherapy, IMRT, and Gamma Knife® techniques, for example) by using 3D geometry phantoms and Magnetic Resonance Imaging (MRI) evaluation technique [1,3].

One of those gel dosimeters that have been very studied [4,5,6,7,8] to be useful for clinical application is the Fricke gel dosimeter. This dosimeter presents many advantages such as: it is easy to prepare, can be molded at any desired shape and size, is tissue equivalent in a wide photon energy range, is applicable in 3D imaging and is non-toxic, non-destructive and non-invasive [9]. The dosimetry is based in the same Fricke conventional dosimetry principle, that is, oxidation of ferrous (Fe^{2+}) to ferric (Fe^{3+}) ions by action of ionizing radiation [4,10]. The gelatine is the gel matrix more employed in Fricke gel dosimeters preparation, and the 300 Bloom gelatine from porcine skin is the most commonly used quality [3,6,8]; however, it is costly to be imported.

In this work dosimetric Fricke gel solutions with different gelatine concentrations and qualities (270 Bloom produced in Brazil and 300 Bloom imported) were prepared and evaluated. Parameters such as color change, consistence, hydrogen potential and response

stability were studied in order to standardize the method for obtaining the Fricke gel solution developed at IPEN, to verify the efficacy of the 270 Bloom gelatine and to become economically viable the clinical use of the Fricke gel solution as dosimeter in Brazil.

2. MATERIALS AND METHODS

2.1. Solutions Preparation

Fricke gel solutions with 1%, 5%, 10% and 15% by weight 270 or 300 Bloom gelatines from porcine skin, tri-distilled water, 50 mM sulphuric acid (H_2SO_4), 1 mM sodium chloride (NaCl), 1 mM ferrous ammonium sulphate hexahydrate [$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$] and 0.1 mM ferric ions indicator xylenol orange ($C_{31}H_{28}N_2Na_4O_{13}S$) [11,12,13] were prepared in accordance with Olsson [14].

Immediately after preparation the solutions were conditioned in Polymethyl Methacrylate (PMMA) cuvettes for samples irradiation and evaluation.

All samples were sealed with Polyvinyl Chloride (PVC) film to minimize the evaporation of the solvent of the solution.

2.2. Samples Irradiation

The solutions were stored under refrigeration at (4 ± 1) °C and light protected for approximately 12 hours [14] and maintained during 30 minutes at room temperature and light protected before irradiation.

The samples of different Fricke gel solutions were irradiated using the ^{60}Co gamma sources: Panoramic (Yoshizawa Kiko® model FIS 60-04) and Gammacell (Atomic Energy of Canada® model 220), of the Intense Radiation Sources Laboratory of IPEN, with absorbed doses between 0.5 and 100.0 Gy. The irradiations were always carried out in free air and under electronic equilibrium conditions.

2.3 Samples Evaluation

A SHIMADZU® model UV-2101PC spectrophotometer of the High Doses Laboratory of IPEN was applied to samples evaluation. The optical absorption measurements were carried out immediately after solutions preparation (non-irradiated solutions) and 30 minutes after irradiation. The dosimetric wavelength for each irradiated solution analyzed was determined and this wavelength was used to obtain the absorbance values. The presented results correspond to the average of absorbance values of three Fricke gel samples and the error bars the standard deviations of the mean. The background value (non-irradiated solution) was subtracted of all average values, except the values used for spectrophotometric response stability determination.

The pH of the solutions was determined using a PHTEK® model PHS-3B bench pH-meter with electrode model E-900 of the High Doses Laboratory of IPEN. To better visualization of color change a EMB® Prendograv negatoscope of the Dosimetric Materials Laboratory of IPEN was used.

3. RESULTS AND DISCUSSIONS

3.1. Gelatine Concentration Influence

In Fig. 1 the spectrophotometric response of Fricke gel solutions prepared with gelatine concentrations of 1%, 5%, 10% and 15% by weight 270 Bloom gelatine irradiated (^{60}Co gamma radiation) with absorbed doses of 5 and 40 Gy is presented.

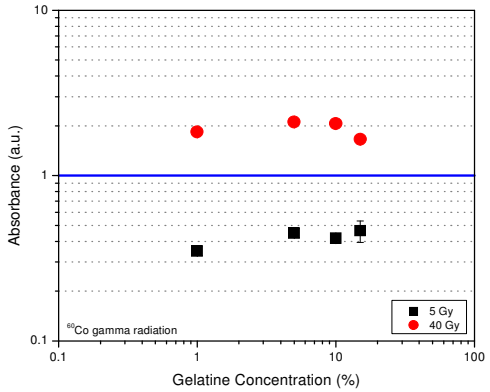


Figure 1. Spectrophotometric response of the Fricke gel solutions (270 Bloom) as a function of gelatine concentration.

The results presented in Fig. 1 correspond to the dosimetric wavelenght of 585 nm.

Comparing the results obtained it is observed that:

- The solution prepared with 1% by weight gelatine presents the lower absorbance values for both radiation doses;
- The solutions prepared with 5% and 10% by weight gelatine exhibit similar behavior to the doses of 5 and 40 Gy;
- The solution prepared with 15% by weight gelatine presents similar behavior to that of solutions prepared with 5% and 10% by weight gelatine to 5 Gy, and the lower absorbance value for dose of 40 Gy. This indicates that the spectrophotometric response of this solution saturates before as consequence of higher gelatine concentration in the solution.

Considering the behavior of the different Fricke gel solutions (Fig. 1) the following comments can be made:

- The solution prepared with 1% by weight gelatine presents no suitable consistence for determining the 3D dose distribution;
- The solution prepared with 10% by weight gelatine shows suitable consistence and sensibility for the dosimetric application but their solidification occurs within some minutes after preparation, what makes more difficult, for example, the filling the reading cuvettes with the dosimetric solution;

- The solution preparation with 15% by weight gelatine is practically unfeasible. The gelatine dissolution is extremely difficult. After the total gelatine dissolution it is impossible to maintain in liquid solution. It is necessary to increase the solution agitation, which creates numerous air bubbles resulting in a non-homogeneous and aerated solution contributing to the increase of natural oxidation of Fe^{2+} ions;
- The solution prepared with 5% by weight gelatine is easy preparation and handling and presents similar behavior compared to the solutions prepared with 10% (for 5 and 40 Gy) and 15% (for 5 Gy) by weight gelatine presenting appropriate sensibility and consistence to determine 3D dose distribution;
- Considering these results the gelatine concentration was fixed in 5% for both gelatine qualities.

3.2. Gelatine Quality Influence

For comparison purposes between the Fricke gel solutions prepared with 5% by weight 270 and 300 Bloom gelatines the following parameters were determined:

- Color change;
- Consistence;
- Hydrogen potential (pH);
- Spectrophotometric response stability as a function of storage time under two different storage conditions:
  - **Condition 1:** under refrigeration ((4 ± 1) °C) and light protected;
  - **Condition 2:** under room temperature and environmental light;

as a function of ^{60}Co gamma dose.

3.2.1. Color change

In Fig. 2 the color change of the non-irradiated and irradiated (dose range between 0.5 to 100.0 Gy) Fricke gel samples prepared with 270 Bloom gelatine (5%) and conditioned in PMMA cuvettes is presented.

This Fricke gel solution prepared with different gelatine concentrations presented the same colors, that change from gold (non-irradiated solution) to dark-violet (100 Gy).

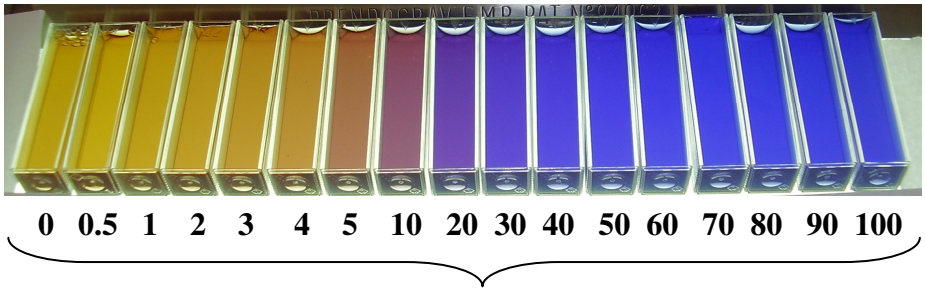


Figure 2. Color range presented to non-irradiated and ^{60}Co gamma irradiated Fricke gel samples (5% by weight 270 Bloom gelatine).

The non-irradiated and irradiated Fricke gel samples prepared with 5% by weight 300 Bloom gelatine presented the same coloration that the solution prepared with 5% by weight 270 Bloom gelatine (Fig. 2).

The colors of Fricke gel solutions were also checked visually and with the aid of a negatoscope.

3.2.2. Consistence

The dosimetric solutions prepared with 270 Bloom gelatine (5%) solidify completely at room temperature within 1 hour after preparation and remained consistent throughout the time that they were used (before and after irradiations and during the spectrophotometric measurements) at the same temperature. The dosimetric solutions prepared with 300 Bloom gelatine (5%) solidify at room temperature within 30 minutes after preparation and they also remained consistent throughout the time of use at the same temperature.

3.2.3. Hydrogen potential – pH

The pH measuring electrode and the temperature sensor of the pH-meter were placed inside the recipient containing the non-irradiated solution immediately after the preparation of each solution. After temperature stabilization (necessary because the pH value varies with the solution temperature) the pH value was measured.

The pH values of the solutions prepared with 270 Bloom gelatine varied from 1.33 (27 °C) for 1% by weight gelatine until 2.47 (31 °C) for 15% by weight gelatine. The temperatures presented are different because the Fricke gel solutions were prepared at room temperature on different days.

The pH of the solution prepared with 5% by weight 300 Bloom gelatine measured was 1.43 (26 °C), similar to that observed for the solution prepared with 270 Bloom gelatine (1.42 to 28 °C).

3.2.4. Response stability

The spectrophotometric response stability as a function of storage time for non-irradiated and irradiated (^{60}Co = 10 Gy) Fricke gel solutions prepared with 270 and 300 Bloom gelatines was studied. The solutions remained under two different storage conditions (described in subsection 3.2) in order to know the response variation of these solutions.

Non-irradiated Fricke gel samples maintained at the condition 1 were removed from the refrigerator and remained at room temperature and light protected (during 30 minutes) before the first spectrophotometric measurement (reading zero). The first measurement of the irradiated samples was carried out 30 minutes after irradiation. After reading the samples were placed under refrigeration ((4 ± 1) °C) again until 30 minutes before the next measurement.

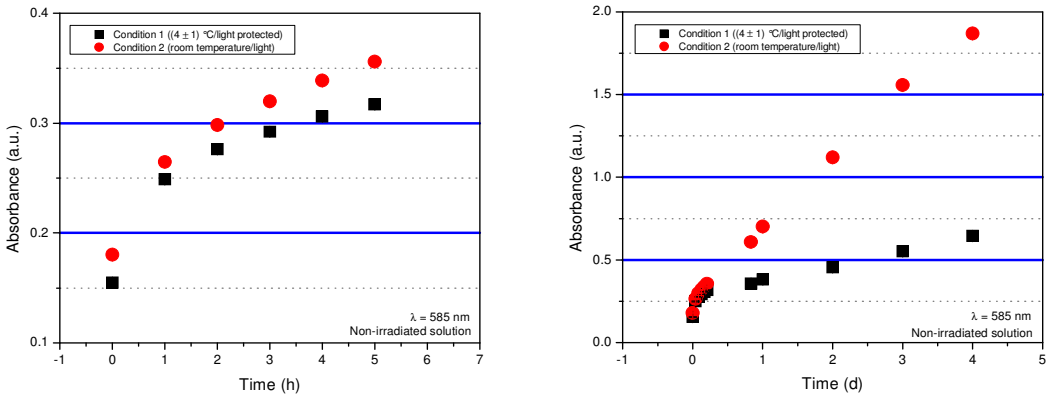
After preparation non-irradiated Fricke gel samples maintained under the condition 2 remained under room temperature and environmental light during the whole analysis period (4 days), even before reading zero. The first measurement of the irradiated samples was also carried out 30 minutes after irradiation. They remained also under room temperature and environmental light during the following measurements.

The measurements of the non-irradiated and irradiated solutions prepared with different gelatine qualities, for both storage conditions, were repeated within the following time:

- Each 1 hour during the first 24 hours;
- 2 times per day, in the second day of analysis;
- Each 24 hours until the end.

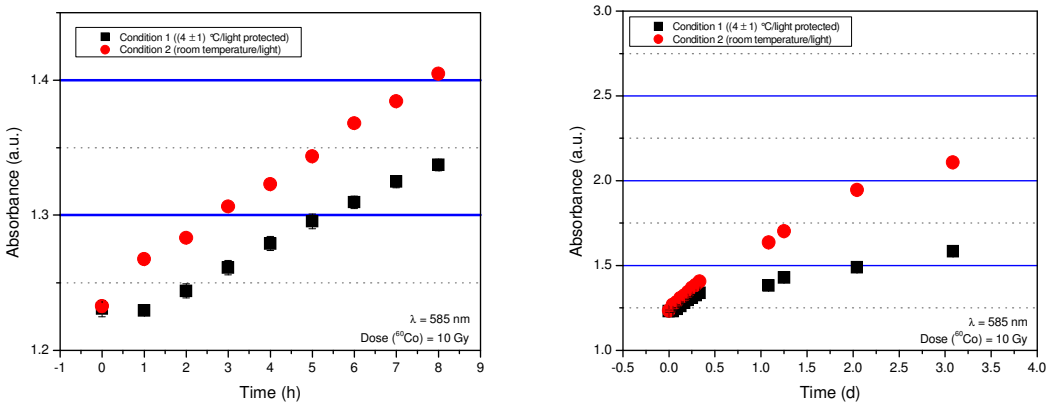
Both dosimetric solutions maintained the solid form at room temperature and no fungi formation was observed during the 4 days of analysis.

In Fig. 3 and 4 the spectrophotometric response stability of non-irradiated and irradiated, respectively, Fricke gel solutions prepared with 270 Bloom gelatine are presented.



a **b**

Figure 3. Spectrophotometric response stability of the non-irradiated Fricke gel solution (270 Bloom gelatine) as a function of storage time in hours (a) and days (b).

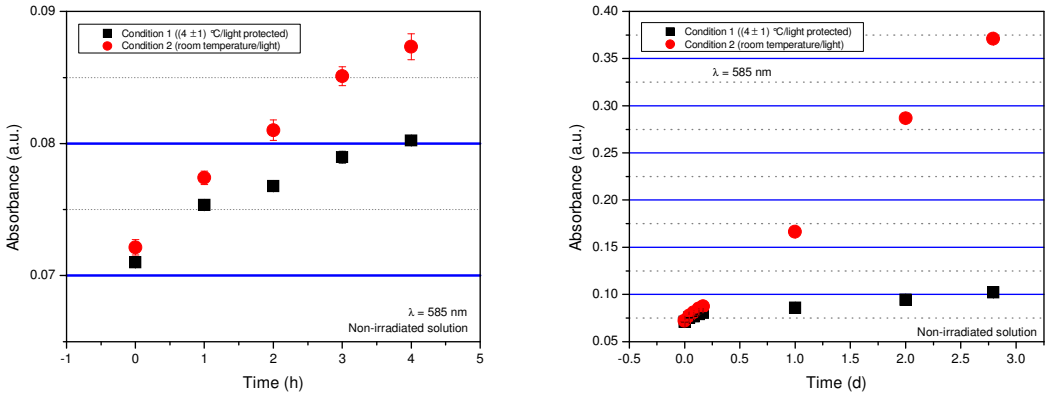


a b

Figure 4. Spectrophotometric response stability of the irradiated Fricke gel solution (270 Bloom gelatine) as a function of storage time in hours (a) and days (b).

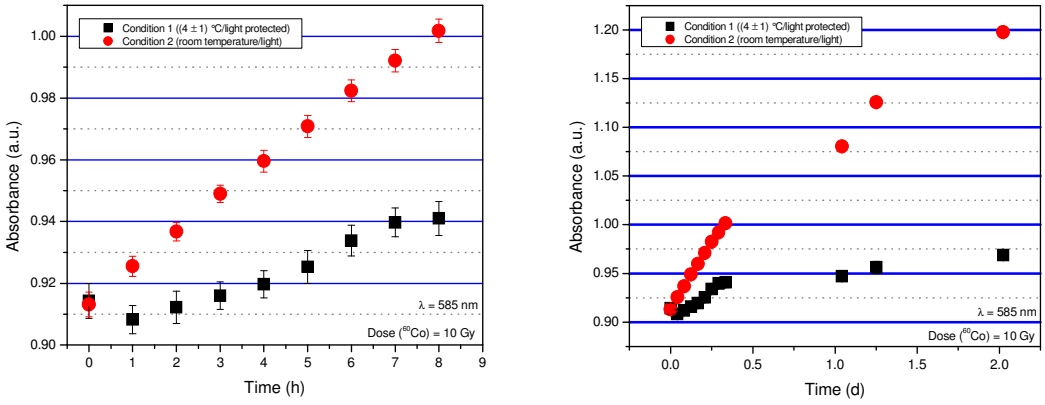
The non-irradiated and irradiated Fricke gel solutions present significant intensification of the absorbance values in both storage conditions studied. This result is explained by the natural oxidation of Fe^{2+} ions present in the solution. This process is accelerated in both cases for the samples maintained in the condition 2.

In Fig. 5 and 6 the results of spectrophotometric response stability of non-irradiated and irradiated, respectively, Fricke gel solutions prepared with 300 Bloom gelatine are presented.



a b

Figure 5. Spectrophotometric response stability of the non-irradiated Fricke gel solution (300 Bloom gelatine) as a function of storage time in hours (a) and days (b).



a b

Figure 6. Spectrophotometric response stability of the irradiated Fricke gel solution (300 Bloom gelatine) as a function of storage time in hours (a) and days (b).

It is observed a similar behavior of that presented by the samples prepared with 270 Bloom gelatine (Fig. 3 and 4). However, the variation between the absorbance values in both storage conditions is lesser.

The samples prepared with both gelatine qualities studied continued being visually observed during 70 days for fungi formation verification in the dosimetric solutions. There was no fungi formation throughout this period for both types of samples.

In conclusion, considering the significant intensification of the spectrophotometric response of the different dosimetric solutions in both storage conditions studied, it is indicated to maintain the Fricke gel solutions under refrigeration and light protected, since the natural oxidation of Fe^{2+} ions is directly proportional to temperature and light exposure (ultraviolet light, especially).

4. CONCLUSIONS

The Fricke gel solutions prepared with 270 and 300 Bloom gelatines present similar behavior for the different parameters studied using spectrophotometry technique and ^{60}Co gamma radiation. Moreover, the 270 Bloom gelatine, made in Brazil, is of easy acquisition in the market and low cost, being about 45 times cheaper than 300 Bloom gelatine.

The results of this work together with the other studies [11,13,15] using the Fricke gel solution prepared with 5% by weight 270 Bloom gelatine from porcine skin indicate that this gelatine quality can replace with advantage the 300 Bloom gelatine imported.

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