Study of Fricke gel dosimeter response for different gel quality

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Abstract. The Fricke xylenol gel (FXG) dosimeter has been studied for application in radiotherapy because it is capable of to measure the spatial distribution of radiation doses. The dosimetry is based on the oxidation of ferrous (Fe$^{2+}$) to ferric (Fe$^{3+}$) ions radiation induced, related to the radiation dose. The gel material usually employed is the 300 Bloom gelatin, which is imported and very expensive in Brazil. Aiming to analyze the viability of to use a locally produced and low cost gel material, in this work the spectrophotometric responses of FXG solutions prepared using 270 Bloom gelatin commercially available and 300 Bloom gelatin imported were compared. The absorption spectra of solutions prepared with 5% by weight 270 and 300 Bloom gelatins non-irradiated and irradiated with $^{60}$Co gamma radiation in the dose range between 0.5 and 100 Gy were analysed, the dose-response curves were evaluated and the useful dose range was established. The obtained results indicate that the FXG solution prepared with 270 Bloom gelatin presents good performance, similar to that presented by the FXG solution prepared with 300 Bloom gelatin and its use can be recommended owing to the low cost and the availability in local market.

1. Introduction
In radiotherapy, radiations sensitive gels have potential as a three-dimensional (3D) dosimeter [1] because are capable of to measure the spatial distribution of radiation doses using the magnetic resonance imaging (MRI) technique [2, 3]. Among others [4, 5, 6, 7] the Fricke xylenol gel (FXG) dosimeter has been very studied by several researches [8, 9, 10, 11] since 1984 [12], when was developed. The FXG dosimetry is based in oxidative conversion of ferrous (Fe$^{2+}$) to ferric (Fe$^{3+}$) ions by ionizing radiation [12].

The spatial integrity of the dose distribution in the FXG dosimeter is maintained by gel matrix present in the dosimeter because it restricts the diffusion of the ferrous and ferric ions [3, 13]. Usually, the gel matrix employed in gel dosimeters is the 300 Bloom gelatin [2, 14, 15], imported and very expensive in Brazil.

The purpose of this work is to analyze the spectrophotometric response of FXG solution prepared with 270 Bloom gelatin commercially available, locally produced and of low cost compared to FXG solution prepared with 300 Bloom gelatin imported.

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2. Materials and methods

2.1. FXG preparation
The Fricke gel solutions were prepared using 5\% by weight 270 or 300 Bloom gelatins, tri-distilled water, 50 mM H\textsubscript{2}SO\textsubscript{4}, 1 mM NaCl, 1 mM ferrous ammonium sulphate hexahydrate or Mohr salt \([\text{Fe(NH}_4\text{)}_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}]\) and 0.1 mM ferric ions indicator xylenol orange \((C_31H_{28}N_2Na_4O_{13}S)\) [8, 10].

Immediately after preparation the non-irradiated Fricke gel solutions were conditioned in acrylic cuvettes (10 mm of the optical path length) for the spectrophotometric measurements. The samples were maintained under refrigeration \((4^\circ C \pm 1^\circ C)\) and light protected during 12 h before irradiation.

2.2. FXG samples irradiation
Thirty minutes before irradiation the dosimeters were maintained at room temperature (~ 25\(^\circ \)C) and light protected. The FXG samples were irradiated in two different \(^{60}\text{Co}\) gamma radiation sources (Panoramic 20 TBq and Gammacell 220 110 TBq) pertaining to Radiation Technology Centre of IPEN-CNEN/SP with absorbed doses between 0.5 and 100 Gy, dose rates of 0.031, 0.0307, 2.47 and 2.44 kGy/h, free air and electronic equilibrium conditions.

The optical measurements were performed thirty minutes after irradiation.

2.3. Evaluation
The spectrophotometry technique [9, 16, 17] was used to evaluate the optical responses. The absorption measurements were performed in the optical range between 190 and 900 nm using SHIMADZU UV-2101PC spectrophotometer.

2.4. Parameters studied
The absorption spectra of solutions prepared with 5\% by weight 270 and 300 Bloom gelatins non-irradiated and irradiated with \(^{60}\text{Co}\) gamma radiation in the dose range between 0.5 and 100 Gy were analysed, the dose-response curves were evaluated and the useful dose range was established.

3. Results and discussions
The presented data in all dose-response curves correspond to the arithmetic mean of three FXG samples for each absorbed dose studied and they present uncertainties that were calculated based in the standard deviation times coverage factor \(k = 3\) providing a reliable level of 99\%.

3.1. FXG – 270 Bloom
The FXG solution prepared with 270 Bloom gelatin presented one absorption band at 441 nm related to Fe\textsuperscript{2+} ions and other absorption band at 585 nm [2] related to Fe\textsuperscript{3+} ions (figure 1).

![Figure 1. Optical absorption spectra of Fricke gel solution prepared with 270 Bloom gelatin.](image)

The lower dose detection limit was calculated using the equation (1):

\[
D_L = \left[\frac{(\overline{OA}_b - b)}{3\sigma} \right] \times f_{cal}
\]
were $D_L = \text{Lower dose detection limit}$, $\overline{OA_{30}} = \text{Mean optical absorption corresponding to thirty non-irradiated FXG samples}$, $b = \text{Linear coefficient of the line set}$, $\sigma = \text{Standard deviation of the mean}$ and $f_{\text{cal}} = \text{Dose calibration factor}$. The calculated $D_L$ value was found to be equal to 0.5 Gy (figure 2a).

The upper dose limit adopted can be extended up to 30 Gy (figure 2b), the maximum value before saturation of the spectrophotometric response. The results presented correspond to the wavelength of 585 nm.

![Graph (a)](image1)

**Figure 2.** Dose-response curve (a and b) of Fricke gel solution prepared with 270 Bloom gelatin.

### 3.2. FXG – 300 Bloom

The FXG solution prepared with 300 Bloom gelatin presented one absorption band at 438 nm related to Fe$^{2+}$ ions and other absorption band at 585 nm [2] related to Fe$^{3+}$ ions (figure 3).
The lower dose detection limit was calculated using the equation (1) and was found to be equal to 0.5 Gy (figure 4a).

The upper dose limit adopted can be extended up to 30 Gy (figure 4b) the maximum value before saturation of the spectrophotometric response. The results presented correspond to the wavelength of 585 nm.

**Figure 4.** Dose-response curve (a and b) of Fricke gel solution prepared with 300 Bloom gelatin.

### 3.3. Comparison – 270 and 300 Bloom

In the figure 5 the spectra of non-irradiated samples prepared using 270 and 300 Bloom gelatins are compared. It can be observed the presence of small pre-existing Fe$^{3+}$ ions concentration in both Fricke
gel solutions which must be subtracted of irradiated samples. In this work the pre-existing Fe$^{3+}$ ions concentration in different Fricke gel solutions (270 and 300 Bloom) was always subtracted.

The similar dose-response behavior in the dose ranges between 0.5 and 30 Gy of both solutions is presented in figure 6.

![Figure 5. Comparison between the spectra of Fricke gel solutions prepared with 270 and 300 Bloom gelatins.](image1)

![Figure 6. Comparison between the dose-response curves of Fricke gel solutions prepared with 270 and 300 Bloom gelatins.](image2)

4. Conclusions
The obtained results indicate that the 270 Bloom gelatin presents good performance, similar to that presented by solution prepared with 300 Bloom gelatin and its use can be recommended owing to the low cost and the availability in local market.

Acknowledgments
The authors are grateful to the FAPESP, CNPq, CAPES, CNEN and IPEN by the financial support.

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