Characterization of the Spectrophotometric Response of the Fricke Gel Dosimeter produced using 270 Bloom Gelatine to Clinical Electron Beams

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Abstract. The Fricke gel dosimetry has been widely studied for clinical application because it allows the three-dimensional (3D) dose verification when used the magnetic resonance imaging (MRI) technique. The objective of this study is to characterize the spectrophotometric response of the Fricke gel dosimeter developed at IPEN, prepared with 270 Bloom gelatine produced in Brazil for clinical electron beams with energies of 4, 6, 9, 12 and 16 MeV to the reference depth using water phantom. The optical absorption spectra, dosimetric wavelength, dose dependent response, lower detection limit, energy dependent response and reproducibility were the parameters studied.

Introduction

The Fricke gel dosimetry allows 3D dose verification when using the MRI technique, in addition to the well-established optical absorption (OA) spectrophotometry technique and therefore has been very studied for clinical application [1-3]. The ferrous ions (Fe^{2+}) initially present in the Fricke gel dosimeter oxidize forming ferric ions (Fe^{3+}) when subjected to ionizing radiation, in proportion to the absorbed dose [1].

In order to enable the implementation of this dosimetry method in radiotherapy and radiosurgery in medical establishments throughout Brazil, the High Doses Laboratory of IPEN developed and characterized for gamma and X radiations and high-energy clinical photons [4-9] fields application, a Fricke xylenol gel (FXG) solution prepared using 270 Bloom gelatine from porcine skin produced in Brazil, of low cost and easy acquisition in the local market, replacing the FXG solution produced using 300 Bloom gelatine (also from porcine skin), used by different researchers, which is imported, of difficult acquisition and with cost about forty-five times higher than the 270 Bloom gelatine.

An important treatment modality in modern radiotherapy is represented by megavoltage electron beams (high-energy accelerators, typically provide various electron beams energies in the range between 4 and 22 MeV) which are often the only treatment option for superficial tumors (less than 5 cm deep) [10]. According to the International Atomic Energy Agency (IAEA), the water is the recommended mean of reference for measurements in electron beams. The water phantom should cover at least 5 cm beyond all four sides of the largest field size employed at the depth of measurement [11].

This work aims to characterize the spectrophotometric response of the Fricke gel dosimeter developed at IPEN, prepared using 270 Bloom gelatine, for clinical electron beams with energies of 4, 6, 9, 12 and 16 MeV to the reference depth using a water phantom.

Materials and Methods

Dosimetric Solutions Preparation

According to Olsson [12], 400 ml of Fricke gel solution using 5% by weight of 270 Bloom gelatine from porcine skin (food and pharmaceutical) (GELITA®), ultra-pure water (ELGA® model PURELAB Option Q DV 25 water purifier), 50 mM of sulphuric acid (H_2SO_4), 1 mM of sodium chloride (NaCl), 1 mM of ferrous ammonium sulphate hexahydrate or Mohr's salt [$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$] and 0.1 mM of xylenol orange ($C_{31}H_{28}N_2Na_4O_{13}S$), which is Fe^{3+} ions indicator, were prepared. All chemical reagents (MERCK®) are of analytical grade.

The FXG samples were conditioned in polymethyl methacrylate (PMMA) cuvettes (SARSTEDT®), with two parallel optical faces, whose dimensions and optical path length are 10 x 10 x 45 mm^3 and 10 mm respectively, and were individually sealed with polyvinyl chloride (PVC) film.

The samples were stored under refrigeration ((4 ± 1) °C) and light protected during 14 h [12] after preparation and maintained 30 min at room temperature and light protected before irradiation.

Samples Irradiation

The Fricke gel solution samples were irradiated in the reading cuvettes using a water phantom. To avoid contact of the FXG solution with water, each three samples set was packed with PVC film (Fig. 1).

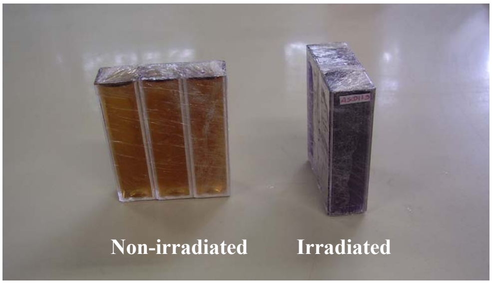

Fig. 1. Sample sets of Fricke gel solution conditioned in PMMA cuvettes, packed with PVC film for irradiation in water

All samples were irradiated with clinical electron beams using a VARIAN® model CLINAC 2100C clinical electrons linear accelerator (Fig. 2a) of the Radiotherapy Unit of the Cancer Center of the Hospital Israelita Albert Einstein (HIAE), with different doses and energies using a radiation field size of 10 x 10 cm^2 and different reference depth to ensure the maximum dose in the center of each FXG sample. The irradiation parameters are shown in Table 1. The temperature, humidity and atmospheric pressure of the irradiation room were maintained at 21° C, 55% and 695 mmHg, repectively, during the irradiations.

Table 1. Irradiation parameters of FXG samples in the CLINAC 2100C accelerator

FXG SAMPLES (270 BLOOM GELATINE) IRRADIATION			
Determination of the Dose Dependent Response			
Nominal Energy (MeV)	Reference Depth (cm/water)	Dose (Gy)	Dose Rate ($cGy.min^{-1}$)
16	2.0	0.05	400
		0.1	
		0.2	
		0.3	
		0.4	
		0.5	
		1.0	
		4.0	
		10.0	
		15.0	
		21.0	

FXG SAMPLES (270 BLOOM GELATINE) IRRADIATION			
Determination of the Energy Dependent Response			
Nominal Energy (MeV)	Reference Depth (cm/water)	Dose (Gy)	Dose Rate ($cGy.min^{-1}$)
4	0.6	9.65 ± 2.05	400
6	0.8	10.1 ± 0.6	
9	1.2	9.2 ± 0.4	
12	2.0	9.85 ± 0.07	
16	2.0	10	

To perform the irradiations a PMMA (ρ = 1.19 $g.cm^{-3}$) box with dimensions 24 x 33 x 12 cm^3 and walls 0.5 cm thick filled with filtered water was used as water phantom (Fig. 2b). To ensure the backscatter two Bolus plates (ρ = 1.03 $g.cm^{-3}$) (CVICO®) model MTCB410S) 1 cm thick and measuring 30 x 30 cm^2 each (Fig. 2b) were placed inside the phantom. In each irradiation a three samples set of Fricke gel solution (Fig. 1) was placed on the two Bolus plates, in the center of the water phantom. To prevent the sample sets immersion they were supported by two acrylic plates 0.8 cm thick each, positioned on the upper and lower extremities of the sets, as shown in Fig. 2b.

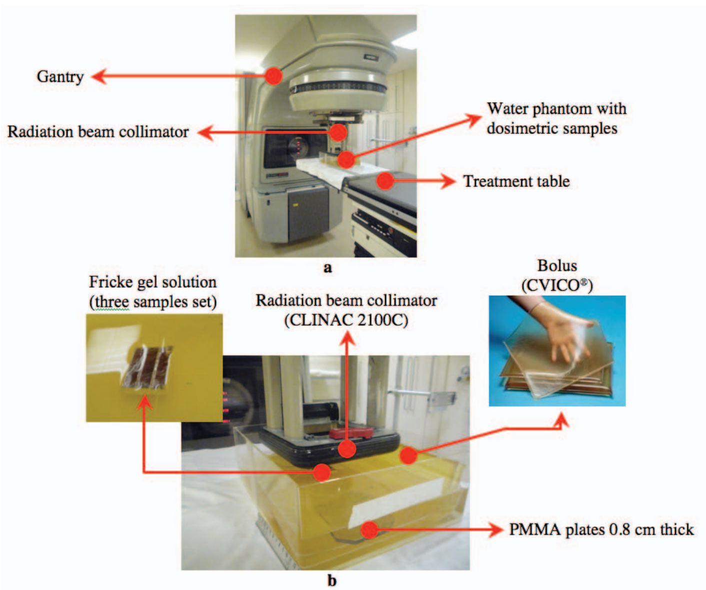

Fig. 2. Experimental set up for FXG samples irradiation in the CLINAC 2100C accelerator (a) and water phantom used for the irradiations (b)

Samples Evaluation

The OA spectrophotometry evaluation technique was used in this study. The measurements were performed using SHIMADZU® model UV-2101PC spectrophotometer (High Doses Laboratory of IPEN) immediately after dosimetric solution preparation and about 30 min after irradiation. The dosimetric wavelength was determined for each irradiated sample analyzed. This wavelength was used to obtain the absorbance values of the irradiated samples.

The color change of the FXG solution (0-21 Gy) was also observed with the aid of an E.M.B.® model PRENDOGRAV lightbox (Dosimetric Materials Laboratory of IPEN).

The optical absorption spectra, dosimetric wavelength, dose dependent response, useful dose range, lower detection limit, energy dependent response and intra-batch reproducibility were evaluated.

The presented spectrophotometric responses correspond to the average of absorbance values of three samples and the error bars the standard deviations of the mean (type B uncertainties were not considered). The background value (non-irradiated samples) was subtracted from all absorbance values.

Results and Discussion

Dose Dependent Response

The color change of the FXG solution, conditioned in PMMA cuvettes, non-irradiated and irradiated with clinical electron beams (16 MeV) with doses of 0.05-21 Gy (clinical dose range) is presented in Fig. 3. The sample color range from yellow-gold (non-irradiated solution) to violet (21 Gy) and note that, visually, there is no color difference between non-irradiated and irradiated (up to 1 Gy) samples.

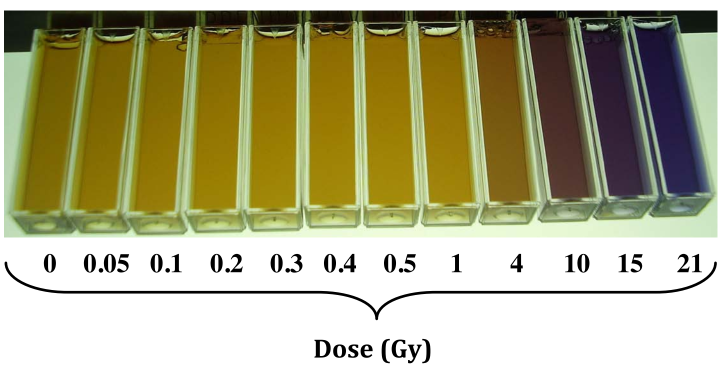

Fig. 3. Colors scale presented by FXG solution non-irradiated and irradiated with 16 MeV clinical electron beams (0.05-21 Gy)

The optical absorption spectra obtained from samples non-irradiated and irradiated with clinical electron beams (16 MeV) and dose range from 0.05 to 21 Gy is presented in Fig. 4.

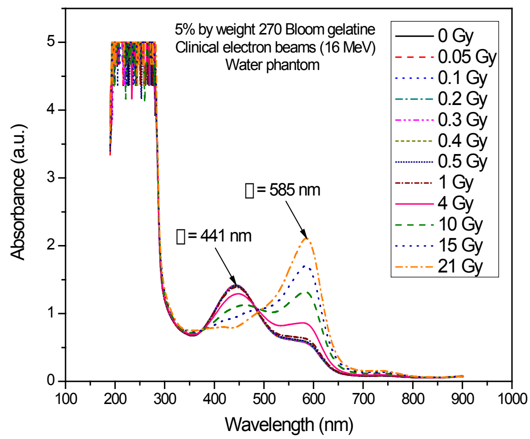

Fig. 4. Optical absorption spectra of FXG samples non-irradiated and irradiated with clinical electron beams

The solution prepared with 270 Bloom gelatine presents two absorption bands, as expected: one at 441 nm, corresponding to Fe^{2+} ions initially present in Fricke gel solution and other at 585 nm, corresponding to Fe^{3+} ions generated by oxidation of Fe^{2+} ions radiation induced. It is observed intensification of absorbance values of the band at 585 nm with increasing radiation dose while the absorption band at 441 nm tends to disappear (Fig. 4) depending on the dose. Comparing the spectra of irradiated dosimetric samples was fixed dosimetric wavelength of 585 nm, the same established by Bero [2].

The spectrophotometric response curve of the FXG solution irradiated with clinical electron beams (16 MeV and dose range 0.05-21 Gy) in function of dose is presented in Fig. 5. Fricke gel solution presents a linear response over the dose range studied.

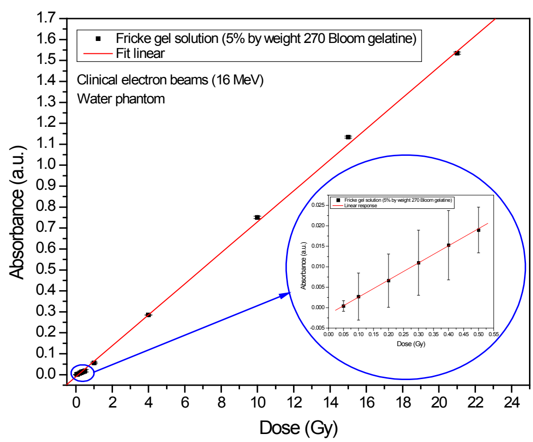

Fig. 5. Spectrophotometric response of the FXG solution in function of electron dose

Lower Detection Limit

The experimental lower detection limit was obtained irradiating the FXG samples with 0.05 Gy, which is the lowest dose obtained with the CLINAC 2100C accelerator. For practical purposes, the lower detection limit for clinical electron beams will be considered 0.05 Gy.

The optical response of the FXG solution to electron energy range from 4 to 16 MeV is presented in Table 2.

Table 2. Optical response of the FXG solution to different electron energies studied

Electron Energy (MeV)	Optical Response (Gy^{-1})
4	0.06
6	0.08
9	0.08
12	0.08
16	0.08

Energy Dependent Response

The OA spectra obtained from samples non-irradiated and irradiated with clinical electron beams with dose of 10 Gy and energies between 4 and 16 MeV are presented in Fig. 6.

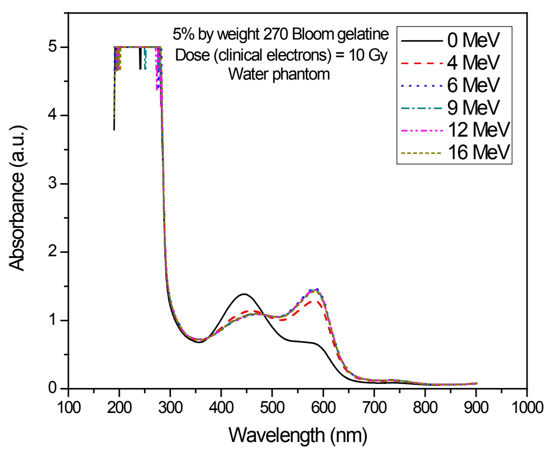

Fig. 6. Optical absorption spectra of FXG samples non-irradiated and irradiated with clinical electron beams

The energy dependent spectrophotometric response curve relative to 16 MeV electrons of the Fricke gel solution irradiated with energy range from 4 to 16 MeV and dose of 10 Gy is presented in Fig. 7.

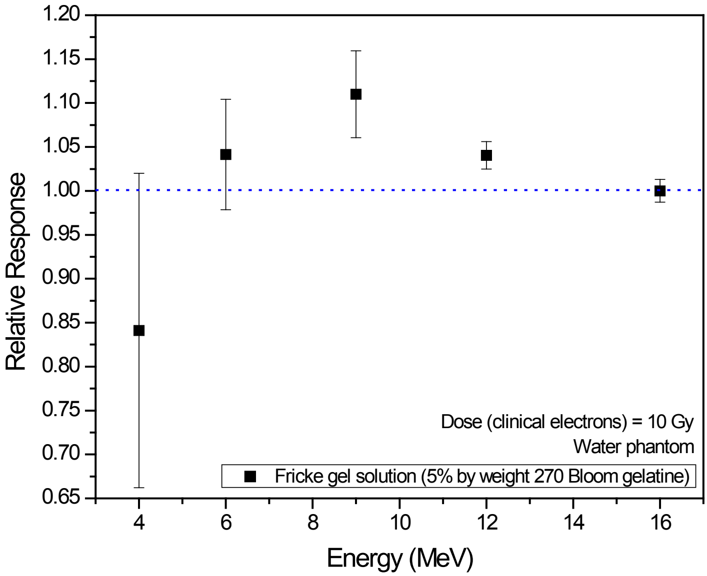

Fig. 7. Energy dependent spectrophotometric response of the Fricke gel solution irradiated with clinical electron beams

The spectrophotometric response of the FXG solution presents maximum dependence of ≅ 10% for the nominal energy of 9 MeV in the energy range studied. For energies greater than ≅ 12 MeV no energy dependent spectrophotometric response is observed. The results obtained to electrons energy of 4 MeV present a large uncertainty due to the dose gradient in the FXG sample set ranging from 11.1 to 8.2 Gy [mean dose value = (9.65 ± 2.05) Gy] due to the fast decrease of dose as a function of the reference depth (cm/water) that occurs on irradiations with low energy electrons, so it was not possible to evaluate the energy dependence satisfactorily.

Reproducibility

To evaluate the intra-batch reproducibility of the FXG solution irradiated with clinical electron beams (1 Gy and 16 MeV) measurements of 5 sample sets subjected to the same experimental conditions were performed. The intra-batch reproducibility obtained is better than ± 3%.

Conclusions

The Fricke gel dosimeter developed at IPEN prepared with 270 Bloom gelatine produced in Brazil provides excellent results when irradiated with clinical electron beams with regard to its behavior in terms of absorbed dose and incident radiation energy. All results obtained in this study are similar to those obtained for ^{60}Co gamma radiation [4], which indicates that the studied solution can be an useful option for quality control of treatments of tumors smaller than 5 cm deep, using clinical electron beams.

The obtained results also indicative the viability of employ this dosimeter in electron 3D dosimetry as has been observed in radiosurgery dosimetry using the Gamma Knife® technique [5].

Acknowledgements

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References

1. Gore, J.C., Kang, Y.S., Schulz, R.J.: Measurement of radiation dose distributions by nuclear magnetic resonance (NMR) imaging. Phys. Med. Biol. (1984) 1189-1197
2. Bero, M.A., Gilboy, W.B., Glover, P.M.: Radiochromic gel dosemeter for three-dimensional dosimetry. Radiat. Phys. Chem. (2001) 433-435
3. Ibbott, G.S.: Clinical applications of gel dosimeters. J. Phys. Conf. Ser. (2006) 108-131
4. Cavinato, C.C.: Padronização do método de dosimetria Fricke gel e avaliação tridimensional de dose empregando a técnica de imageamento por ressonância magnética. Instituto de Pesquisas Energéticas e Nucleares (2009)
5. Cavinato, C.C., Rodrigues Jr., O., Cervantes, J.H., Rabbani, S.R., Campos, L.L.: A dosimetric evaluation of tissue equivalent phantom prepared using 270 Bloom gelatin for absorbed dose imaging in Gamma Knife radiosurgery. J. Phys. Conf. Ser. (2009) doi:10.1088/1742-6596/164/1/012016
6. Cavinato, C.C., Campos, L.L.: Energy dependent response of the Fricke gel dosimeter prepared with 270 Bloom gelatine for photons in the energy range 13.93 keV–6MeV. Nucl. Instr. and Meth. A. (2009) doi:10.1016/j.nima.2009.10.144
7. Cavinato, C.C., Campos, L.L.: Study of Fricke gel dosimeter response for different gel quality. J. Phys. Conf. Ser. (2009) Accepted for publication
8. Galante, A.M.S., Cervantes, H.J., Cavinato, C.C., Campos, L.L., Rabbani, S.R.: MRI study of radiation effect on Fricke gel solutions. Radiat. Meas. (2008) 550-553

9. Galante, A.M.S., Campos, L.L.: Chemical dosimeters development at IPEN for the radiation processes quality control. In: Camilleri, A.N. (ed.): Radiation physics research progress. Nova Science (2008) 355–384
10. Strydom, W., Parker, W., Olivares, M.: Electron beams: physical and clinical aspects. In: Podgorsak, E.B. (ed.): Radiation oncology physics: a handbook for teachers and students. International Atomic Energy Agency (2005) 273-299
11. Andreo, P., Burns, D.T., Hohlfeld, K., Huq, M.S., Kanai, T., Laitano, F., Smyth, V., Vynckier, S.: Absorbed dose determination in external beam radiotherapy: an international code of practice for dosimetry based on standards of absorbed dose to water. International Atomic Energy Agency (2004)
12. Olsson, L.E., Petersson, S., Ahlgren, L., Mattsson, S.: Ferrous sulphate gels for determination of absorbed dose distributions using MRI technique: basic studies. Phys. Med. Biol. (1989) 43-52