Spectrophotometric response of the Fricke gel dosimeter developed at IPEN for clinical electron beams

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Abstract

Fricke gel dosimeter is one of the gel dosimeters that have been widely studied for application to clinical dosimetry. This work aims to evaluate the performance of the Fricke gel dosimeter developed at IPEN, prepared with 270 Bloom gelatine from porcine skin made in Brazil, for clinical electron beams from a VARIAN® electron linear accelerator in the energy range from 6 to 16 MeV to reference depth, using a water phantom and spectrophotometry technique. The following parameters were studied: color change, intra and inter batches reproducibility, dose response, dose rate and angular dependent response and response stability in function of storage time under two different conditions: 1) refrigeration and light protected and 2) room temperature and environment light. The excellent results obtained in this study indicate that the studied FXG solution can be a useful option for quality control of treatments of superficial tumours, using clinical electron beams.

Introduction

Different techniques and dosimetric materials have been widely studied because of the increasing demand for efficiency and safety in radiotherapy and radiosurgery treatments. The gel dosimetry has been highlighted because dosimeters can be shaped in three dimensions (3D) and different sizes and shapes so that they become very useful for complex dosimetry techniques such as intensity-modulated radiation therapy (IMRT) (Ibbott 2006).

Among the currently studied gel dosimeters is the Fricke gel dosimeter which is based on the oxidation of ferrous (Fe^{2+}) to ferric (Fe^{3+}) ions by action of ionizing radiation. Its response can be measured by optical absorption (OA) spectrophotometry and magnetic resonance imaging (MRI) evaluation techniques (Gore et al. 1984).

In this work the performance of the Fricke xylenol gel (FXG) dosimeter developed at IPEN, prepared with 270 Bloom gelatine from porcine skin made in Brazil, for clinical electron beams from a VARIAN® electron linear accelerator in energy range from 6 to 16 MeV to reference depth, using a water phantom and OA spectrophotometry technique was evaluated. Different parameters were studied namely: color change; intra and inter-batches reproducibility; dose response, dose rate and

angular dependent response and response stability in function of storage time under two different conditions: 1) refrigeration and light protected and 2) room temperature and environment light.

Materials and methods

FXG solutions preparation

Different batches of Fricke gel solution using 5% by weight of 270 Bloom gelatine from porcine skin (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 ($C_{31}H_{28}N_2Na_4O_{13}S$) were prepared (Olsson et al. 1989). The chemical reagents (MERCK®) are of analytical grade.

The Fricke gel samples were conditioned in polymethyl methacrylate (PMMA) cuvettes (SARSTEDT®), with two parallel optical faces, dimensions of 10 x 10 x 45 mm^3 and optical path length of 10 mm and were individually sealed with polyvinyl chloride (PVC) film. The samples were stored under refrigeration ((4 ± 1) °C) and light protected during about 12 h (Olsson et al. 1989) after preparation and maintained 30 min at room temperature and light protected before irradiation.

FXG samples irradiation

The Fricke gel solution samples were irradiated in the reading cuvettes using a water phantom. Each three samples set of Fricke gel solution was packed with PVC film (Fig. 1) in order to avoid contact of the FXG solution with water. A 40 x 40 x 40 cm^3 MEDINTEC® water phantom filled with tri-distilled water was used to samples irradiation (Fig. 2).

Fig. 1. Three samples set of FXG solution packed with PVC film.

The samples were irradiated with clinical electron beams using a VARIAN® clinical electrons linear accelerator model CLINAC 2100C (Fig. 2) of the Radiotherapy Unit of the Cancer Centre of the Hospital Israelita Albert Einstein (HIAE), with electron energies between 6 and 16 MeV, absorbed doses from 0.05 to 21 Gy, dose rates from 80 to 400 cGy/min, irradiation angles between 0º and 180º, using a radiation field size of 10 x 10 cm^2 and different reference depth (0.6 to 2.0 cm/water) to ensure the maximum dose in the centre of each FXG sample. The temperature, humidity and atmospheric pressure of the irradiation room were maintained at 21° C, 55% and 697 mmHg, respectively, during the irradiations.

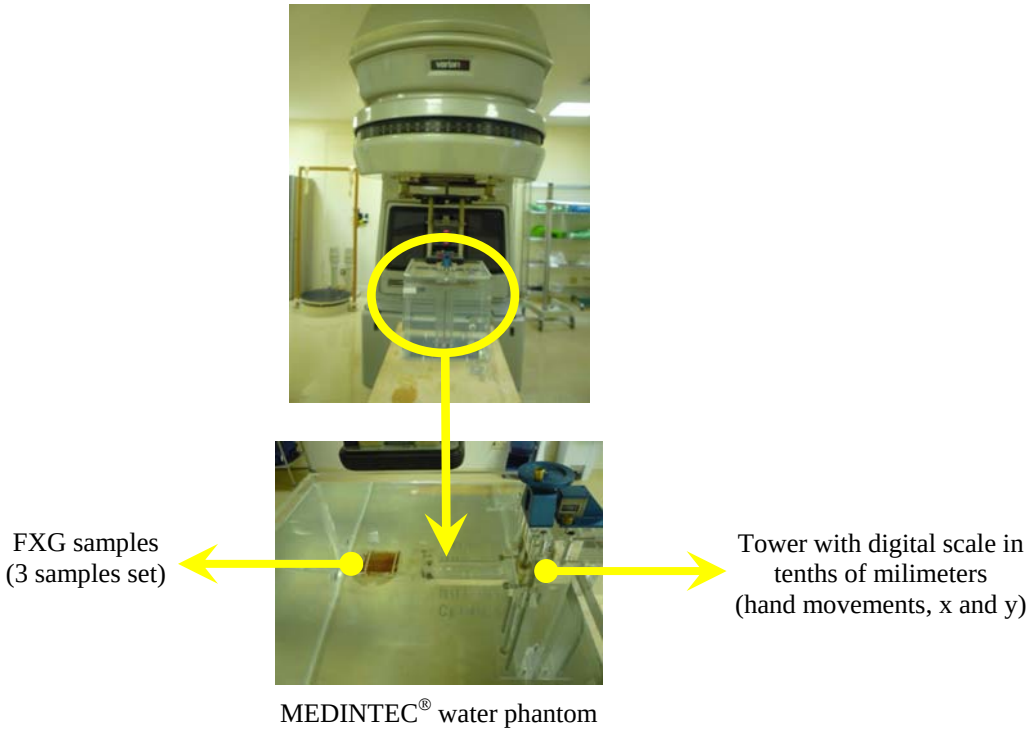

Fig. 2. Experimental set up for FXG samples irradiation in VARIAN® linear accelerator (CLINAC 2100C) using a water phantom.

OA evaluation

The OA spectrophotometry evaluation technique was used in this study. The measurements were performed using SHIMADZU® spectrophotometer model UV-2101PC (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 following parameters were studied: color change (using an E.M.B.® lightbox model PRENDOGRAV of IPEN); intra and inter-batches reproducibility; dose response, dose rate and angular dependent response and response stability in function of storage time under two different conditions: 1) refrigeration and light protected and 2) room temperature and environment light.

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

Colour change

The colour change of the Fricke gel solution (in PMMA cuvettes) non-irradiated and irradiated with clinical electron beams with doses from 0.05 to 21 Gy, 12 MeV and 400 cGy/min is presented in Fig. 3. The samples present colour range from yellow-

gold (non-irradiated solution) to violet (21 Gy) and the same colours are presented by FXG solutions irradiated with the others electron energies and dose rates studied.

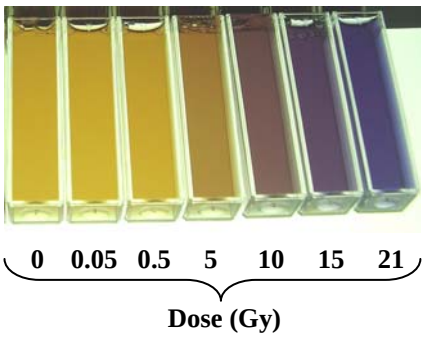

Fig. 3. Colour range presented by Fricke gel solution non-irradiated and irradiated with doses between 0.05 and 21 Gy.

Intra and inter-batches 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 (Cavinato et al. 2010).

Five batches of 100 mL of FXG solution were prepared in the same day and under same experimental conditions in order to evaluate the inter-batches reproducibility of the dosimetric solution studied. These solutions were also irradiated with clinical electron beams (1 Gy and 16 MeV) and the optical measurements of samples were performed.

The intra and inter-batches reproducibility obtained is better than ± 3% (Cavinato et al. 2010) and ± 2%, respectively.

Dose response

The optical absorption spectra and spectrophotometric dose-response curve obtained of the FXG solution irradiated with clinical electron beams (12 MeV and dose range from 0.05 to 21 Gy) is presented in Fig. 4.

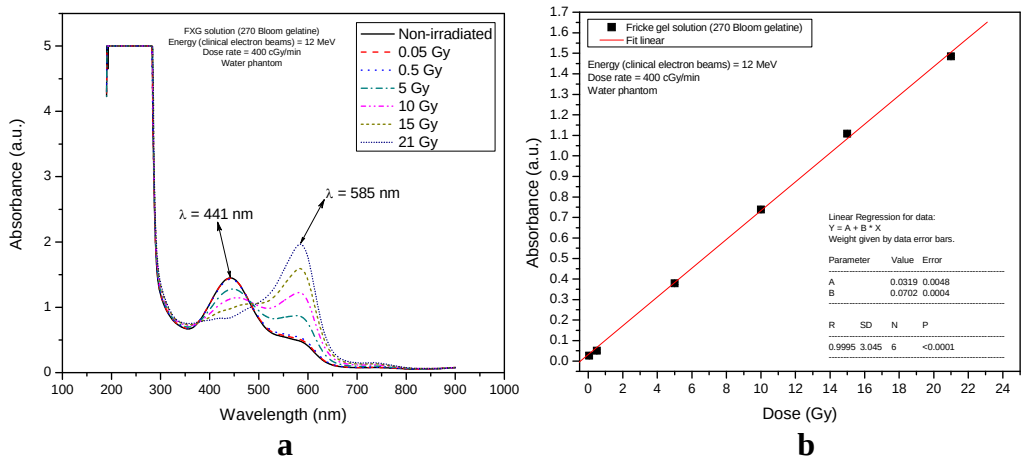

Fig. 4. Optical absorption spectra of FXG samples non-irradiated and irradiated with clinical electron beam (a) and dose-response curve of the FXG solution (b).

The solution prepared with 270 Bloom gelatine presents two absorption bands, as expected: one at 441 nm (Fe^{2+}) and other at 585 nm (Fe^{3+}) generated by induced oxidation of Fe^{2+} ions by ionizing radiation. It is observed intensification of absorbance values of the band at 585 nm (Bero et al. 2001) with increasing radiation dose while the absorption band at 441 nm tends to disappear (Fig. 4a) depending on the dose.

The Fricke gel solution presents a linear response over the dose range studied (Fig. 4b).

Dose rate

The dose rate dependent response (relative to higher absorbance value) of the FXG solution irradiated with 12 MeV, 10 Gy and dose rates from 80 to 400 cGy/min is presented in Fig. 5. The dose rate dependent response obtained is better than ± 3%.

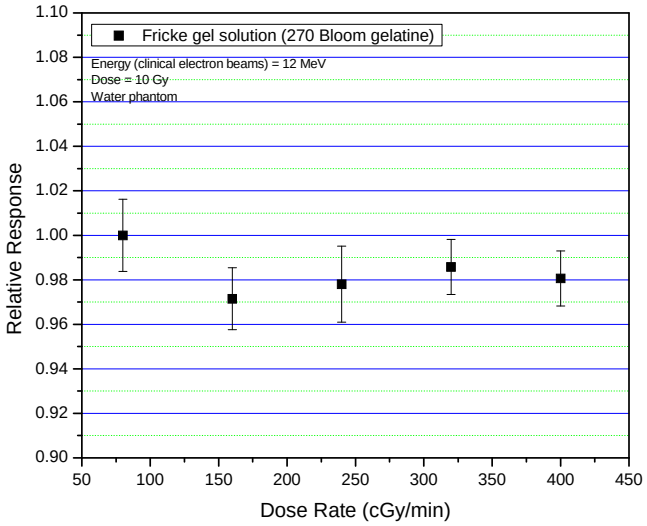

Fig. 5. Dose rate dependent response of the FXG solution irradiated with clinical electron beams.

Angular response

The angular dependent response (relative to higher absorbance value) of the Fricke gel solution irradiated with 6 and 12 MeV, 10 Gy and irradiation angles from 0º to 180º is presented in Fig. 6. The angular dependent response obtained for electron energies of 6 and 12 MeV is less than 1%.

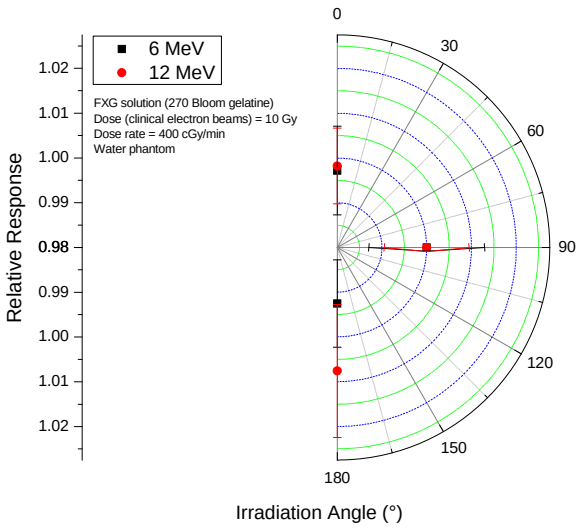

Fig. 6. Angular dependent response of the Fricke gel solution irradiated with clinical electron beams.

Response stability

The response stability of the FXG solution non-irradiated and irradiated (16 MeV and 1 Gy) in function of storage time under the conditions 1 and 2 studied (refrigeration and light protected, room temperature and environment light, respectively) is presented in Fig. 7.

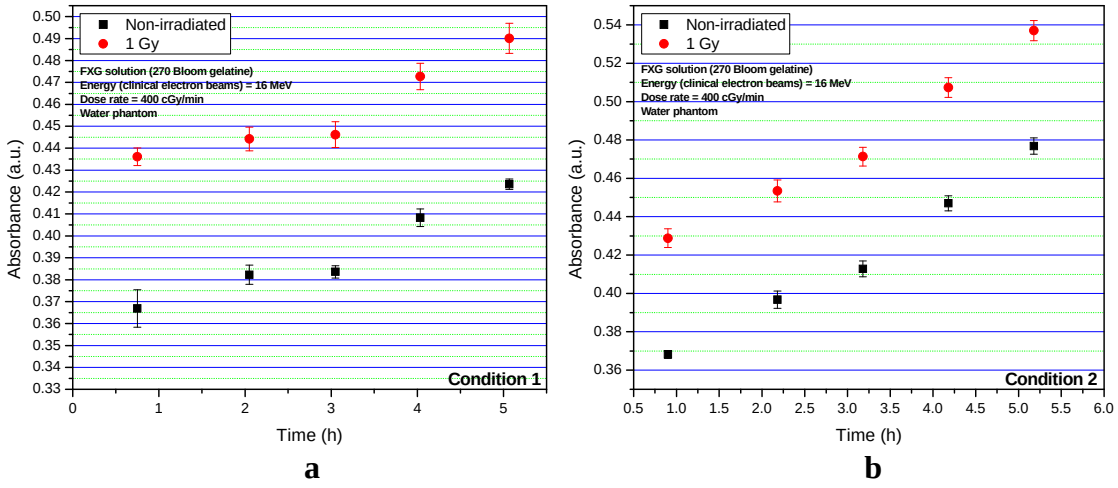

Fig. 7. Response stability of the Fricke gel solution non-irradiated and irradiated (clinical electron beams) in function of storage time under conditions 1 (a) and 2 (b).

It can be observed that in both storage conditions occurs intensification of absorbance values over time. However, for the non-irradiated and irradiated solution, there is a variation of the spectrophotometric response of less than 5% for conditions 1 (up to 4 hours after irradiation) and 2 (up to 3 hours after irradiation). Thus, the dosimetric samples should always be kept under refrigeration and light protected.

The energy dependent response previously studied (Cavinato et al. 2010) is better than ± 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.

Conclusions

The Fricke gel dosimeter developed at IPEN prepared with 270 Bloom gelatine produced in Brazil provides excellent results when irradiated with different energies, absorbed doses and dose rates of clinical electron beams. The results obtained in this study complement previous work using clinical electron beams (Cavinato et al. 2010) and indicate that the studied FXG solution can be a useful option for quality control of treatments of superficial tumours, using clinical electron beams. The obtained results also indicative the viability of employ this dosimeter in electron 3D dosimetry.

Acknowledgements

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