RESPONSE CHARACTERIZATION OF THE FXG DOSIMETER DEVELOPED AT IPEN TO DIFFERENT CLINICAL PHOTON ENERGIES

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ABSTRACT

In this study the spectrophotometric response of the Fricke xylenol gel (FXG) dosimeter developed at IPEN irradiated with different clinical photon energies using a water phantom was characterized. This dosimeter presents satisfactory results in the clinical photon energy range between 6 and 18 MV with respect to the parameters studied and it can be used as optional dosimeter for quality control in the radiotherapy and radiosurgery treatment planning.

Key words: FXG dosimeter; clinical photon beams; water phantom.

RESUMO

Neste estudo foi caracterizada a resposta espectrofotométrica do dosímetro Fricke xilenol gel (FXG) desenvolvido no IPEN irradiado com diferentes energias de feixes de fótons clínicos, utilizando um simulador de água. Este dosímetro apresenta resultados satisfatórios no intervalo de energia de feixes de fótons clínicos entre 6 e 18 MV em relação aos parâmetros estudados e pode ser usado como um dosímetro opcional para o controle de qualidade no planejamento de tratamentos radioterápicos e radiocirúrgicos.

Descritores: Dosímetro Fricke gel; feixes de fótons clínicos; simulador de água.

INTRODUCTION

The gel dosimetry is a highly promising relative dosimetry method and useful for absorbed dose verification in complex clinical situations (e.g. Intensity Modulated Radiotherapy – IMRT) using three-dimensional geometry phantoms [1]. The Fricke gel dosimeter meets the requirements for application in three-dimensional dosimetry, very useful in radiotherapy and radiosurgery. The Fricke gel dosimeter characteristics and all variables related to their performance must be evaluated and determined the precision and accuracy of its response [2,3,4].

In this work several parameters of FXG dosimeter developed at IPEN, prepared using 270 Bloom national gelatine were studied in order to evaluate its performance to different clinical photon energies.

MATERIALS AND METHODS OF ANALYSIS

FXG solutions preparation. Different batches of FXG solution were prepared using 5% by weight 270 Bloom gelatine from porcine skin, ultra-pure 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 xylenol orange ($C_{31}H_{28}N_2Na_4O_{13}S$). The dosimetric solutions were conditioned in polymethyl methacrylate (PMMA) cuvettes with 10 mm of optical path length.

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

The irradiations were performed on VARIAN® linear accelerators models CLINAC 2100C and CLINAC 23EX of Hospital Israelita Albert Einstein, using a 40 x 40 x 40 cm^3 MEDINTEC® water phantom filled with tri-distilled water. Each three samples set of Fricke gel solution was packed with polyvinyl chloride (PVC) film (Figure 1) in order to avoid contact of the FXG solution with water.

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

The FXG samples sets were irradiated with clinical photon beams, dose range between 0.05 and 21 Gy, dose rates from 100 to 600 cGy/min and energy range between 6 and 18 MV using a radiation field size of 10 x 10 cm^2 and reference depth of 5 cm/water to ensure the maximum dose in the center of each FXG sample.

Samples evaluation. The optical absorption (OA) spectrophotometry evaluation technique and SHIMADZU® spectrophotometer model UV-2101PC of IPEN were used. To observe the colour change of the FXG samples an E.M.B.® model PRENDOGRAV lightbox (IPEN) was used.

The optical measurements were performed about 30 min after irradiation and the dosimetric wavelength was determined after analyzing all irradiated samples.

The following parameters were studied: colour change; optical absorption spectra; intra and inter-batches reproducibility; dose response curves; lower detection limit; energy, dose rate and angle dependent response and response stability in function of storage time under two different conditions: 1) low temperature 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 FXG solution, conditioned in PMMA cuvettes, non-irradiated and irradiated with clinical photon beams (6-18 MV) with doses of 0.05 to 21 Gy is presented in Figure 2. The colour range extends from yellow-gold (non-irradiated solution) to violet (21 Gy).

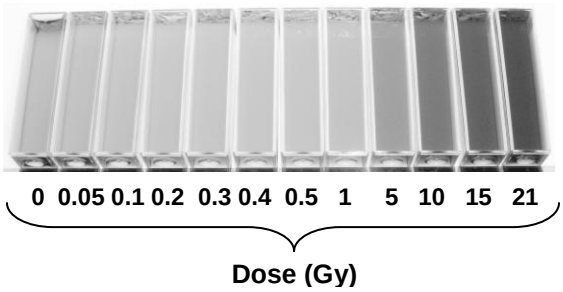

Figure 2: Colours scale presented by FXG solution non-irradiated and irradiated with different photon doses and energies (6-18 MV).

Optical absorption spectra. The optical absorption spectra obtained from FXG samples non-irradiated and irradiated with clinical photon beams (15 MV) and dose range from 0.05 to 21 Gy is presented in Figure 3.

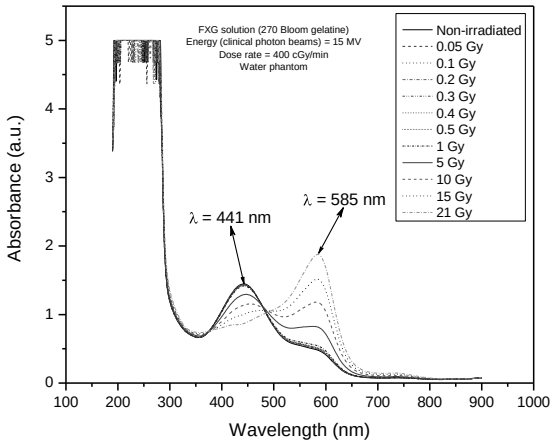

Figure 3: Optical absorption spectra of FXG samples non-irradiated and irradiated with clinical photon beams.

As expected, the solution prepared with 270 Bloom gelatine presents two absorption bands: 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 radiation induced Fe^{2+} ions oxidation. 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 (Figure 3) depending on the dose. Comparing the spectra of irradiated dosimetric samples was fixed dosimetric wavelength of 585 nm, the same established by Bero [3].

The optical absorption spectra of FXG samples irradiated with photon energies of 6 and 18 MV present the same behaviour observed in Figure 3.

Intra and inter-batches reproducibility. To evaluate the intra and inter-batches reproducibility of the FXG solution, the samples were irradiated with photon energies of 6, 15 and 18 MV and dose of 1 Gy. Measurements of 5 sample sets with 3 cuvettes each one of a single batch, subjected to the same experimental conditions were performed. The intra-batch reproducibility obtained is better than 1%. The inter-batches reproducibility was evaluated to 4 sample sets with 3 cuvettes each one of different batches subjected to the same experimental conditions. The inter-batches reproducibility obtained is better than 5%.

Dose response curves. The spectrophotometric response curves of FXG solution irradiated with clinical photon beams (0.05-21 Gy and 6-18 MV) in function of dose is presented in Figure 4.

Fricke gel solution presents a linear behaviour over the dose range studied to photon energies of 15 and 18 MV; above 15 Gy to 6 MV photons tends to saturation. The difference between the optical responses obtained for different photon energies studied is due to energy dependent spectrophotometric response of FXG dosimeter.

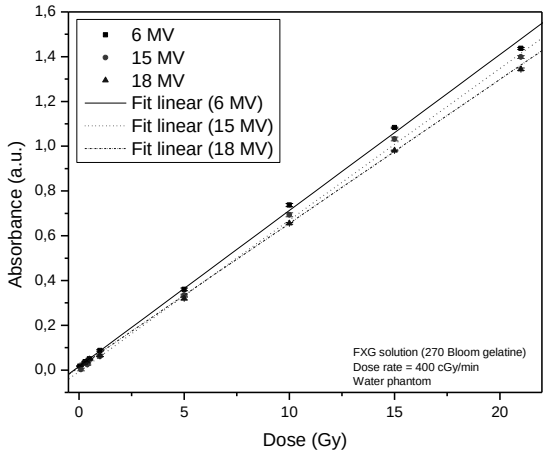

Figure 4: Spectrophotometric response curves of the FXG solution in function of photon dose for 6, 15 and 18 MV.

Lower detection limit. The experimental lower detection limit was established irradiating the FXG samples with 0.05 Gy, which is the lowest dose obtained with the CLINAC 2100C and 23EX accelerators. The lower detection limit for clinical photon beams will be considered 0.05 Gy for practical purposes.

Energy dependent response. The energy dependent spectrophotometric response curve relative to average absorbance value of the Fricke gel solution irradiated with photon energy range from 6 to 18 MV and dose of 10 Gy is presented in Figure 5. The spectrophotometric response of the FXG solution presents maximum variation of ± 3% relative to average absorbance value. These results indicate that the spectrophotometric response of the

studied solution can be considered energy independent in this energy range.

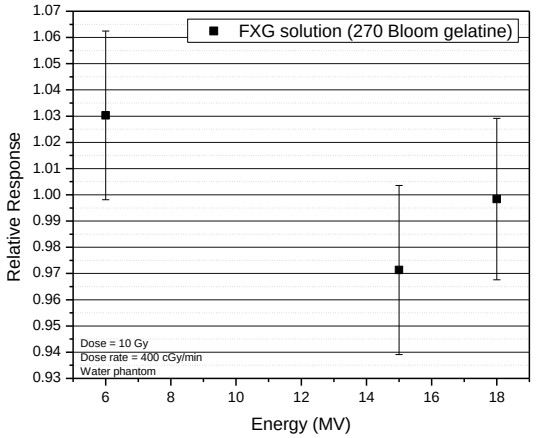

Figure 5: Energy dependent spectrophotometric response of the Fricke gel solution irradiated with clinical photon beams.

Dose rate dependent response. The dose rate dependent response (relative to average absorbance value) of the FXG solution irradiated with 15 MV photons, 2 Gy and dose rates from 100 to 600 cGy/min is presented in Figure 6. The dose rate dependent response obtained is better than ± 5%.

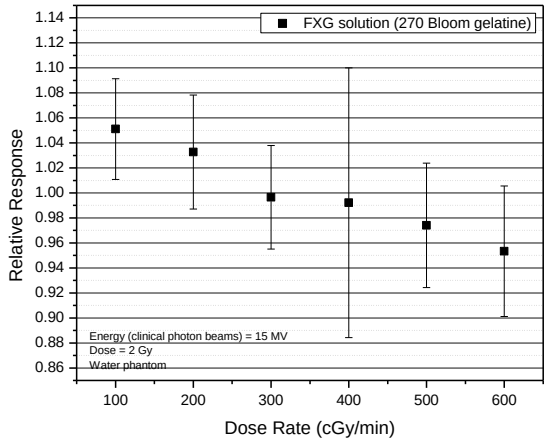

Figure 6: Dose rate dependent response of the FXG solution irradiated with clinical photon beams.

Angle dependent response. The angle dependent response (relative to average absorbance value) of the Fricke gel solution irradiated with 15 MV photons, 2 Gy and incidence angles from 0º to 270º is presented in Figure 7. The angle dependent response obtained for photon energy of 15 MV is better than 3%. These results indicate that the spectrophotometric response of the studied solution can be considered angle independent in this incidence angle range.

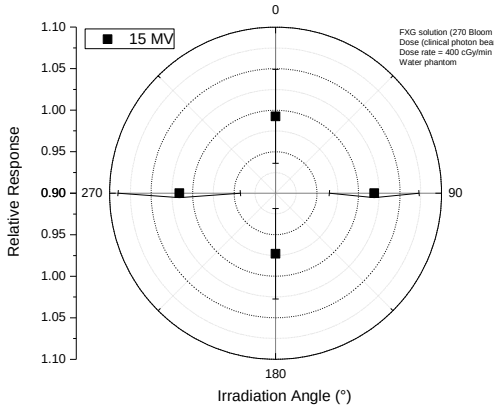

Figure 7: Angle dependent response of the Fricke gel solution irradiated with clinical photon beams.

Response stability. The response stability of the FXG solution non-irradiated and irradiated (15 MV and 1 Gy) in function of storage time under the conditions 1 and 2 studied (low temperature and light protected; room temperature and environment light, respectively) is presented in Figure 8.

In both storage conditions occurs intensification of absorbance values over time. However, there is a variation of the spectrophotometric response of less than 5% for conditions 1 (up to 7 hours after irradiation) and 2 (up to 1 hour after irradiation), for both non-irradiated and irradiated solutions. Thus, the dosimetric samples should always be kept under low temperature and light protected.

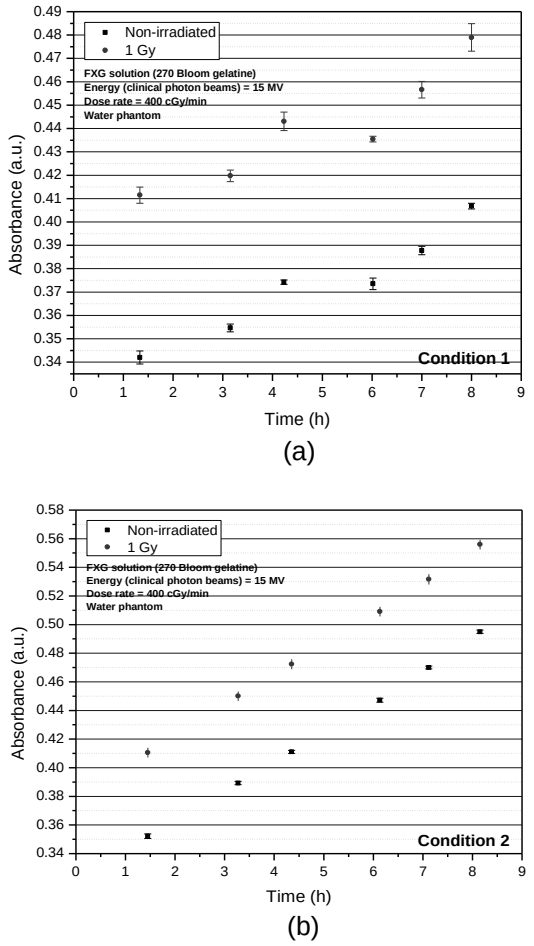

Figure 8: Response stability of the Fricke gel solution non-irradiated and irradiated (clinical photon beams) in function of storage time under conditions 1 (a) and 2 (b).

CONCLUSIONS

The FXG dosimeter developed at IPEN, prepared using 270 Bloom national gelatine, presents satisfactory results for clinical photon energies from 6 to 18 MV with respect to the parameters studied in this work and therefore, it can be used as optional dosimeter for quality control in the radiotherapy and radiosurgery treatment planning.

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