Comparative study of spectrophotometric response of the 270 Bloom Fricke gel dosimeter to clinical photon and electron beams

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Abstract. This study aims to compare the spectrophotometric response of the Fricke xylenol gel (FXG) dosimeter developed at IPEN, prepared using 270 Bloom gelatine from porcine skin produced in Brazil, for clinical photons 6 to 18 MV and electron beams with energies between 6 to 16 MeV, to the reference depth using liquid and virtual water phantoms. The optical absorption spectra, dosimetric wavelengths, energy and dose dependent response, sensitivity and lower detection limits were evaluated and compared for both clinical beams. All results obtained in this study are satisfactory and indicate the viability of implementing this dosimeter in photon and electron 3D dosimetry.

1. Introduction

Linear accelerators have been very used to treat the more differentiated tumours with clinical photon (deep seated tumours) and electron (superficial tumours) beams. With the increasing use of accelerators, has been required a quality control (QC) of the treatment planning increasingly efficient in order to optimize clinical results [1, 2]. The Fricke gel dosimeter, which dosimetry is based on the oxidation of ferrous (Fe^{2+}) to ferric (Fe^{3+}) ions by ionizing radiation, has been widely studied for application to QC of radiation treatments by allowing the three-dimensional dose distribution verification [3–5].

The High Doses Laboratory of IPEN developed a Fricke xylenol gel (FXG) dosimeter prepared using 270 Bloom gelatine from porcine skin produced in Brazil [6] low cost and easy on the national market, replacing the FXG solution produced using 300 Bloom gelatine which is imported, hard to acquire and high-priced, about forty-five times more expensive [7].

This work aims to compare the spectrophotometric response of the FXG dosimeter developed at IPEN, prepared using 270 Bloom gelatine, for clinical photons 6 to 18 MV and electron beams with energies between 6 to 16 MeV, to the reference depths using liquid and virtual water phantoms [8]. The optical absorption spectra, dosimetric wavelengths, energy and dose dependent response, sensitivity and lower detection limits were evaluated and compared for both clinical beams.

2. Materials and methods

2.1. Fricke gel solutions preparation

The FXG solutions were prepared using 5% by weight of 270 Bloom gelatine, ultra-pure water, 50 mM of sulphuric acid, 1 mM of sodium chloride, 1 mM of ferrous ammonium sulphate hexahydrate and 0.1 mM of xylenol orange [3]. The samples were conditioned in polymethyl methacrylate (PMMA) cuvettes ($10 \times 10 \times 45$ mm^3) and stored under refrigeration ((4 ± 1) °C) and light protected during about 12 h [3] after preparation and maintained 30 min at room temperature and light protected before irradiation.

2.2. Fricke gel samples irradiation

The samples were irradiated in the reading cuvettes with clinical photon beams 6 to 18 MV (VARIAN® linear accelerator models CLINAC 2100C and CLINAC 23EX) and electron beams with energies between 6 to 16 MeV (VARIAN® linear accelerator model CLINAC 2100C) with absorbed doses between 0.05 and 40 Gy and dose rate of 400 cGy·min^{-1} using radiation field size of 10×10 cm^2.

A MEDINTEC® liquid water phantom [PMMA walls and bottom $40 \times 40 \times 40$ cm^3 filled with tri-distilled water ($\rho = 1.00$ g·cm^{-3})] was used for all irradiations. In order to avoid contact of the dosimetric solution with tri-distilled water, all three samples sets of FXG solution were packed with polyvinyl chloride (PVC) film.

Irradiations with 6 MV photons and 12 MeV electrons were repeated using a CIVCO® virtual water ($\rho = 1.03$ g·cm^{-3}) phantom (plates of different thicknesses measuring 30×30 cm^2), wich is a solid phantom consisting of water-equivalent plastic, to compare with the results obtained using the liquid water phantom.

To ensure the maximum dose in the centre of each FXG sample different reference depths were used (Table I). In Table I also are presented the backscatter for photon and electron irradiations.

Table I. Reference depths and backscatter thicknesses for photon and electron irradiations

Clinical Beams	**Energy**	**Liquid Water Phantom (cm·liquid water^{-1})**		**Virtual Water Phantom (cm·virtual water^{-1})**	
		Reference Depth	**Backscatter Thickness**	**Reference Depth**	**Backscatter Thickness**
Photons	6 MV 15 MV 18 MV	5.0	5.0	4.4	5.0
Electrons	6 MeV	0.8	5.0	–	–
	9 MeV	1.4		–	–
	12 MeV	2.4		2.4	5.0
	16 MeV	2.0		–	–

2.3. Fricke gel samples evaluation

The evaluation technique used was the optical absorption (OA) spectrophotometry and the measurements were performed using SHIMADZU® spectrophotometer model UV-2101PC.

3. Results and discussion

Each presented value corresponds to the average of the measurement of three samples and the error bars the standard deviation of the mean. The background values corresponding to the optical measurements of non-irradiated FXG samples were subtracted from all absorbance values presented.

3.1. Optical absorption spectra and dosimetric wavelength

The optical absorption spectra obtained to FXG solutions non-irradiated and irradiated with 6 MV photon and 12 MeV electron beams using a liquid water phantom are presented in Figs 1 and 2, repectively.

The FXG solutions irradiated with photon and electron beams present two absorption bands, as expected: one at 441 nm, corresponding to Fe^{2+} ions initially present in non-irradiated Fricke gel solution and other at 585 nm, corresponding to Fe^{3+} ions generated by oxidation of Fe^{2+} ions by ionizing radiation. The absorption band at 441 nm tends to disappear while the band at 585 nm increases with radiation dose.

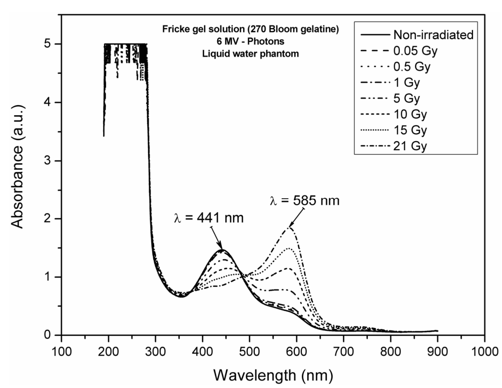

FIG. 1. *Optical absorption spectra of the Fricke gel solution non-irradiated and irradiated with clinical photon beams.*

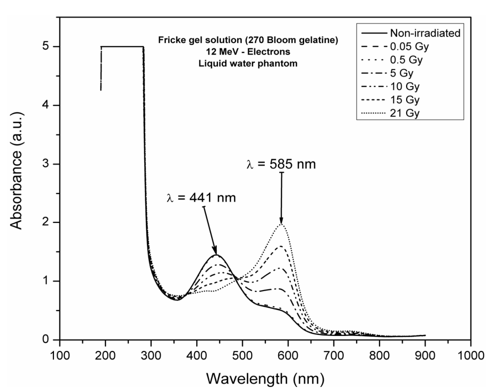

FIG. 2. Optical absorption spectra of the Fricke gel solution non-irradiated and irradiated with clinical electron beams.

The optical absorption spectra of the Fricke gel samples irradiated with the different studied photon and electron energies and phantom materials also exhibit this behaviour. Therefore, the dosimetric wavelength established for Fricke gel solution is 585 nm, the same presented in literature [4].

3.2. Energy dependent response

The energy dependent response curves for the FXG solutions irradiated with clinical photon beams with energies between 6–18 MV relative to 18 MV photons and irradiated with clinical electron beams with energies between 6–16 MeV relative to 16 MeV electrons using a liquid water phantom are presented in Figs 3 and 4, respectively.

The spectrophotometric response relative to 18 MV photon beams presents maximum dependence of about 7% for 6 MV in the energy range studied and the spectrophotometric response relative to 16 MeV electron beams presents maximum dependence of about 10% for 9 MeV also in the energy range studied.

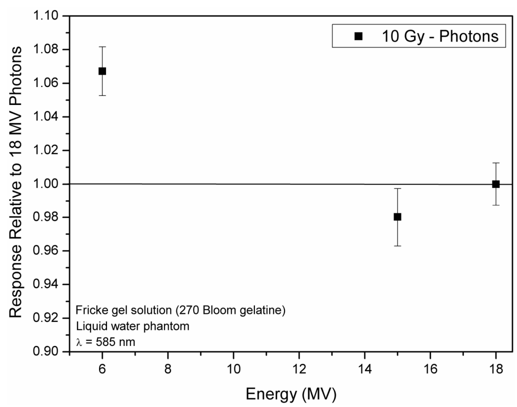

FIG. 3. Energy dependent spectrophotometric response curve of the Fricke gel solutions irradiated with clinical photon beams.

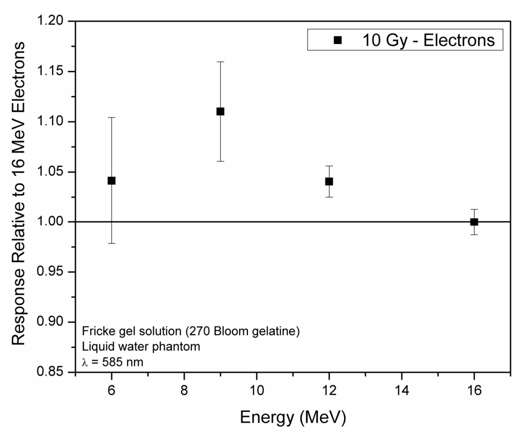

FIG. 4. Energy dependent spectrophotometric response curve of the Fricke gel solutions irradiated with clinical electron beams.

3.3. Dose response curves

The spectrophotometric dose-response curves (corrected to energy dependent response) of the FXG solutions irradiated with 6–18 MV photons and absorbed doses between 0.05 and 40 Gy and 6–16 MeV electrons and absorbed doses between 0.05 and 21 Gy, using liquid and virtual water phantom are presented in Figs 5 and 6, respectively.

The optical response of the FXG solution presented linear behaviour in dose range of 0.05 to 21 Gy (clinical dose range) for photon and electron beams; for absorbed doses higher than 25 Gy occurs spectrophotometric response saturation.

The difference between optical response of Fricke gel solution irradiated using liquid and virtual water phantoms is better than 0.8% for 6 MV photons and 0.5% for 12 MeV electrons.

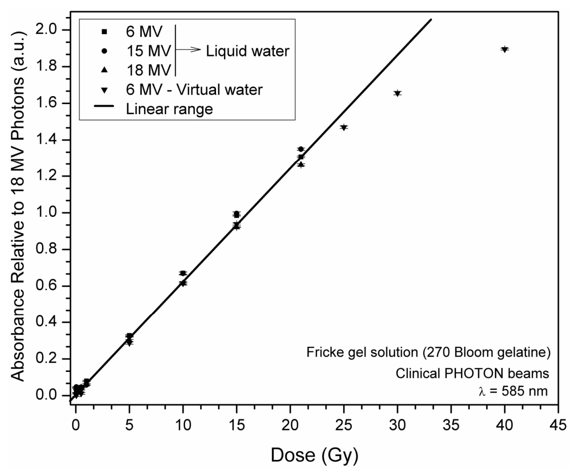

FIG. 5. Spectrophotometric dose-response curve of the Fricke gel solutions irradiated with clinical photon beams using different phantom materials.

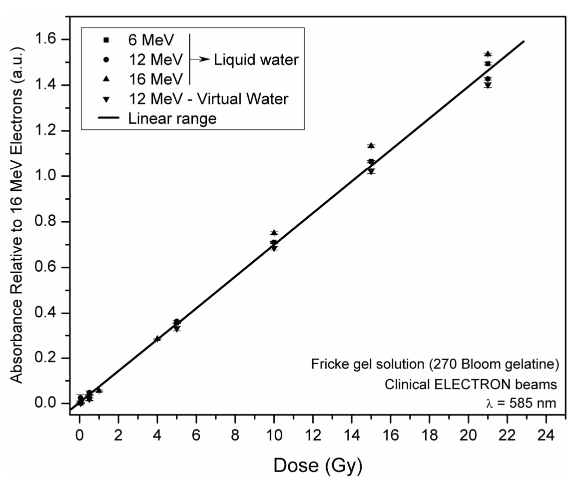

FIG. 6. Spectrophotometric dose-response curve of the Fricke gel solutions irradiated with clinical electron beams using different phantom materials.

Therefore the spectrophotometric response can be considered independent of the phantom material in the energy range studied.

3.4. Sensitivity and lower detection limit

The OA sensitivity for clinical photon beams is $0.06 \pm 0.001\ \text{au}\cdot\text{Gy}^{-1}$ and $0.07 \pm 0.001\ \text{au}\cdot\text{Gy}^{-1}$ for electron beams for the different energies and phantom materials studied.

The lower detection limit experimentally established for photons and electrons was 0.05 Gy in the dose range studied, that is the lowest dose obtained using a clinical accelerator.

4. Conclusions

The obtained results in this study indicate that 270 Bloom FXG dosimeter developed at IPEN provides excellent results when irradiated with different clinical photon and electron energies and phantom materials. All results obtained were similar to those obtained for ^{60}Co gamma radiation [7] and also indicate the viability of implementing this dosimeter in photon and electron 3D dosimetry.

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REFERENCES

[1] PODGORSAK, E.B., “External photon beams: physical aspects”, Radiation Oncology Physics: a Handbook for Teachers and Students, (PODGORSAK, E.B., Ed.), IAEA, Vienna (2005) 161–217.

[2] STRYDOM, W., PARKER, W., OLIVARES, M., “Electron beams: physical and clinical aspects”, Radiation Oncology Physics: a Handbook for Teachers and Students, (PODGORSAK, E.B., Ed.), IAEA, Vienna (2005) 273–299.

[3] OLSSON, L.E., et al., Ferrous sulphate gels for determination of absorbed dose distributions using MRI technique: basic studies, Phys. Med. Biol. **34** 1 (1989) 43.

[4] BERO, M.A., GILBOY, W.B., GLOVER, P.M., Radiochromic gel dosemeter for three-dimensional dosimetry, Radiat. Phys. Chem. **61** (2001) 433.

[5] GORE, J.C., KANG, Y.S., SCHULZ, R.J., Measurement of radiation dose distributions by nuclear magnetic resonance (NMR) imaging, Phys. Med. Biol. **29** 10 (1984) 1189.

[6] GALANTE, A.M.S., et al., MRI study of radiation effect on Fricke gel solutions, Radiat. Meas. **43** (2008) 550.

[7] Cavinato, C.C., Padronização do Método de Dosimetria Fricke Gel e Avaliação Tridimensional de Dose Empregando a Técnica de Imageamento por Ressonância Magnética, Master Dissertation, Univ. of Sao Paulo, Sao Paulo (2009).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Absorbed Dose Determination in External Beam Radiotherapy: an International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water, Technical Reports Series No. 398, IAEA, Vienna (2004).