

# FXG Dosimeter Response for Three-Dimensional Conformal Radiotherapy Using Different Evaluation Techniques

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**Abstract.** This work aims to compare the dose-response of the Fricke xylenol gel (FXG) dosimeter developed at IPEN using 270 Bloom gelatin from porcine skin made in Brazil evaluated using the magnetic resonance imaging (MRI) technique with the dosimetric response evaluated using the optical absorption (OA) spectrophotometry technique, in order to verify the possibility of quality assurance (QA) and reproducibility of FXG dosimeter to be carried out routinely using the OA technique for three-dimensional conformal radiotherapy (3DCRT) application using a 6 MV photons linear accelerator. The response in function of the absorbed dose of FXG dosimeter developed at IPEN presents linear behavior in clinical interest dose range when irradiated with <sup>60</sup>Co gamma radiation and 6 MV photons and evaluated using the MRI and OA techniques. The results indicate that the optical technique can be used for QA of FXG dosimeter when used in the possible application in QA of 3DCRT.

## 1 Introduction

To ensure effective treatment and avoid deadly mistakes to patients is required a rigorous quality assurance (QA) of the complex tumors treatment techniques such as

three-dimensional conformal radiotherapy (3DCRT) and intensity modulated radiotherapy (IMRT) [1]. A dosimetric system that has been extensively studied for this purpose is the Fricke gel dosimetry, considering the ability to produce three-dimensional phantoms of various shapes and sizes [2]. Its dosimetry principle is based in ferrous ( $\text{Fe}^{2+}$ ) to ferric ( $\text{Fe}^{3+}$ ) ions oxidation caused by action of ionizing radiation [3].

This study was performed with the aim of to compare the dose-response of the Fricke xyleneol gel (FXG) dosimeter developed at IPEN using 270 Bloom gelatin from porcine skin made in Brazil evaluated using the magnetic resonance imaging (MRI) technique with the dosimetric response evaluated using the optical absorption (OA) spectrophotometry technique, in order to verify the possibility of quality assurance (QA) and reproducibility of FXG dosimeter to be carried out routinely using the OA technique for three-dimensional conformal radiotherapy (3DCRT) application using a 6 MV photons linear accelerator, considering that OA is a cheap, ease and fast optical evaluation technique.

## 2 Materials and Methods

The FXG samples were prepared at High Doses Laboratory (LDA) of IPEN. The gamma and photon irradiations were carried out in the Radiotherapy Service of the Sao Paulo Hospital (HSP) of UNIFESP, the magnetic resonance images were achieved in the Resonance Magnetic Service at Diagnostic Image Department of HSP (UNIFESP), and the optical absorption measures at LDA.

### 2.1 FXG Solution Preparation

The FXG solutions were prepared according to Olsson [4] using 5% by weight 270 Bloom gelatin from porcine skin, ultra-pure water, 50 mM sulphuric acid ( $\text{H}_2\text{SO}_4$ ), 1 mM sodium chloride (NaCl), 1 mM ferrous ammonium sulphate hexahydrate or Morh's salt [ $\text{Fe}(\text{NH}_4)_2(\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ ] and 0.1 mM xyleneol orange ferric ions indicator ( $\text{C}_{31}\text{H}_{28}\text{N}_2\text{Na}_4\text{O}_{13}\text{S}$ ); the chemicals are analytical grade. The samples were conditioned in polymethylmethacrylate (PMMA) cuvettes  $10 \times 10 \times 45 \text{ mm}^3$  and sets of three samples each were prepared for the irradiations and measurements. The sample sets were packed with polyvinyl chloride (PVC) film to prevent evaporation of the water contained in the Fricke gel solution and to ensure the reproducibility of the dosimetric response of the three FXG samples.

The FXG samples were maintained under low temperature ( $(4 \pm 1)^\circ\text{C}$ ) and light protected during 12:30 h before irradiation.

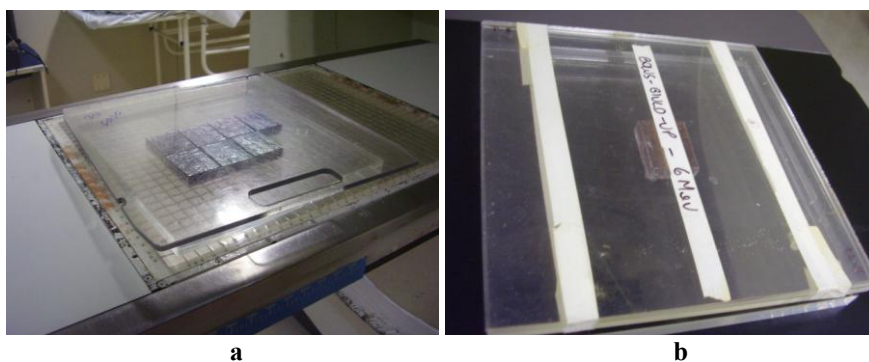
### 2.2 FXG Samples Irradiation

Considering the homogeneity and precision of absorbed dose delivery of  $^{60}\text{Co}$  gamma sources and that the effective photon energy of 6 MV photon beam is approximately 2 MeV, the FXG samples were irradiated with  $^{60}\text{Co}$  gamma radiation, as reference

system, in the dose range of 2 to 20 Gy, dose rate of 74.98 cGy/min, 40 x 40 cm<sup>2</sup> field size and source-surface distance (SSD) of 80 cm using a GENERAL ELECTRIC COMPANY<sup>®</sup> Alcyon II <sup>60</sup>Co gamma radiation (HSP/UNIFESP) using a PMMA plates phantom (build-up and backscattering PMMA plates 1.5 cm thick). All FXG sample sets were positioned together in the PMMA phantom (Fig. 1a) and each set was removed when the radiation exposure time needed to obtain the desired absorbed dose was completed.

Three sample sets were irradiated with 6 MV photons (one at a time), with absorbed doses of 5 to 15 Gy, dose rate of 300 cGy/min, 30 x 30 cm<sup>2</sup> field size and SSD of 92 cm using a VARIAN<sup>®</sup> Clinac 600C linear accelerator (HSP/UNIFESP) and the same PMMA phantom, to compare the obtained results with the dose-response curves obtained for <sup>60</sup>Co gamma radiation. The experimental set up for FXG samples irradiation with 6 MV photons is presented in Fig. 1b.

The dosimetric response in function of the dose rate was also studied, since different irradiation systems can operate with different dose rates. For this study FXG samples were irradiated with <sup>60</sup>Co gamma radiation and 6 MV photons with absorbed dose of 10 Gy and dose rates between 74.98 and 600 cGy/min.



**Fig. 1.** Experimental set up for FXG samples irradiations with <sup>60</sup>Co gamma radiation (a) and 6 MV photons (b)

### 2.3 FXG Samples Evaluation

The dosimetric response of the FXG samples non-irradiated and irradiated with <sup>60</sup>Co gamma radiation and 6 MV photons were evaluated using both magnetic resonance imaging (MRI) and optical absorption (AO) spectrophotometry techniques using a SIEMENS<sup>®</sup> MAGNETOM<sup>®</sup> Sonata Maestro Class 1.5 T MRI scanner (HSP/UNIFESP) and SHIMADZU<sup>®</sup> UV2101-PC spectrophotometer (LDA/IPEN), respectively.

For the FXG MR signal intensity analysis in function of the absorbed dose scans in the coronal orientation of the cuvettes containing the FXG solution non-irradiated and irradiated with <sup>60</sup>Co gamma radiation (dose range of 2 to 20 Gy) were obtained using on cranium protocol-T1 approximately 30 min after irradiation. The MR image acqui-

sition parameters are presented in Table 1. The softwares syngo fastView<sup>®</sup> version VX57F24 and ImageJ<sup>®</sup> version 1.42q were used to process the MRI scans obtained.

All optical measurements were performed in the wavelength range from 190 to 900 nm and achieved about 2 h after irradiations due to the distance between the facilities where the irradiations (HSP/UNIFESP) and measurements (LDA/IPEN) were made. The absorbance values presented correspond to dosimetric wavelength of 585 nm [5,6].

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 magnetic and optical measurements of non-irradiated Fricke gel samples were subtracted from all values presented.

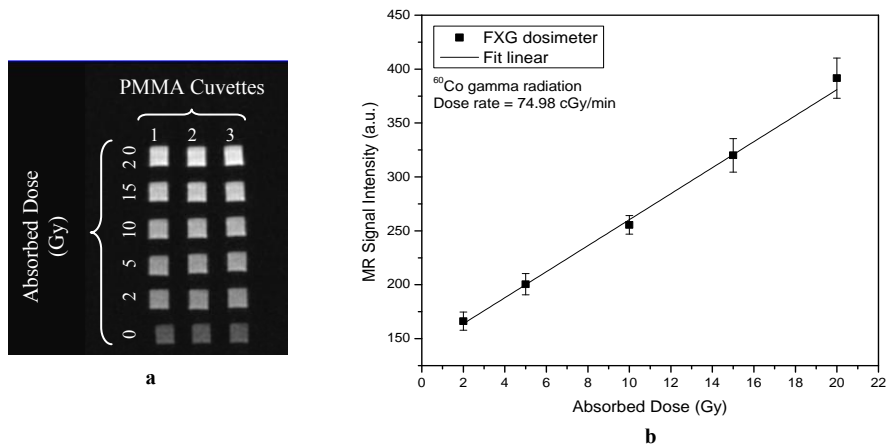
**Table 1.** MR image acquisition parameters

Parameters Description	Values
Image Orientation	Coronal
Field of View (FOV) (mm)	256
Slice Thickness (THK) (mm)	1.0
Voxel (mm)	1.0 x 1.0 x 1.0
Gap (mm)	0.5
Time of Repetition (TR) (ms)	2000
Time of Echo (TE) (ms)	3.42
Flip Angle (°)	15
Matrix Size (MS) (pixels)	256 x 256
Number of Signals Averaged (NSA)	1
Slices Number	176
Coil	Head
Channels	8

### 3 Results and Discussions

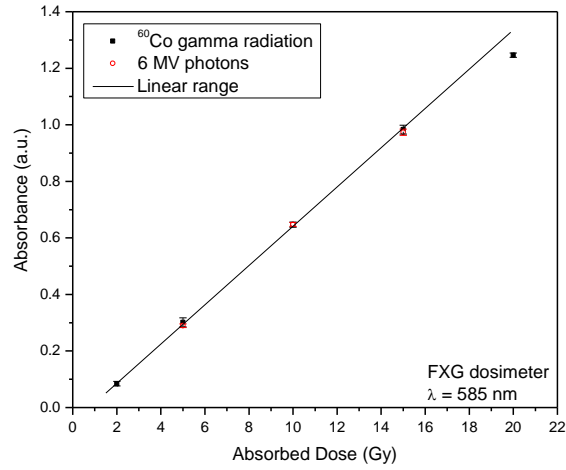
#### 3.1 Magnetic Resonance Imaging *versus* Optical Absorption

**Dose-Response Curves.** The PMMA cuvettes MR images that showed better resolution at the region of interest (ROI) and the corresponding MR signal intensity in function of radiation dose of studied dosimeter non-irradiated and irradiated with  $^{60}\text{Co}$  gamma radiation and absorbed doses of 2 to 20 Gy are presented in Fig. 2.



**Fig. 2.** Coronal MR images of the FXG solution conditioned in PMMA cuvettes non-irradiated and irradiated with  $^{60}\text{Co}$  gamma radiation (a) and MR signal intensity curve in function of absorbed dose of the FXG samples image (b) (modified from Cavinato et al., [7])

The optical dose-response curves of the FXG dosimeter irradiated with  $^{60}\text{Co}$  gamma radiation (74.98 cGy/min) and 6 MV photons (300 cGy/min) and with absorbed doses between 2 and 20 Gy are presented in Fig. 3.

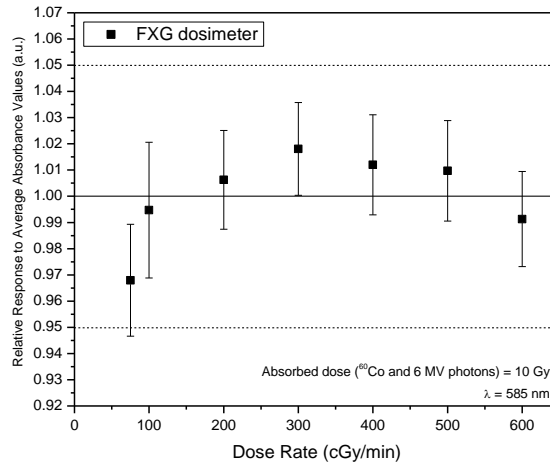


**Fig. 3.** Dose-response curves of FXG samples irradiated with  $^{60}\text{Co}$  gamma radiation and 6 MV photons

The FXG dosimeter response in function of absorbed dose presents linear behavior in the clinical interest dose range when irradiated with  $^{60}\text{Co}$  gamma radiation and 6 MV photons and evaluated with MRI and OA techniques, tending to saturation to doses equal and higher than 20 Gy. The uncertainties are better than  $\pm 2\%$  for OA technique and  $\pm 5\%$  for MRI technique because of quality of MR images.

### 3.2 Dose Rate Curve

The optical response in function of dose rate relative to the average absorbance values of the FXG solution irradiated with  $^{60}\text{Co}$  gamma radiation and 6 MV photons for dose rates from 74.98 to 600 cGy/min and absorbed dose of 10 Gy is presented in Fig. 4.



**Fig. 4.** FXG dose rate dependent optical response curve relative to the average absorbance values irradiated with  $^{60}\text{Co}$  gamma radiation and 6 MV photons

The dose rate dependent response obtained is better than  $\pm 3.5\%$  indicating that the calibration of a FXG phantom developed at IPEN irradiated with 6 MV photons can be performed using a  $^{60}\text{Co}$  gamma radiation clinical machine.

## 4 Conclusions

This study presents good results which indicate that the optical absorption spectrophotometry technique can be used for the quality assurance and reproducibility confirmation of the Fricke xylenol gel dosimeter developed at IPEN applied to 3DCRT.

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