Preliminary Study of the 270 Bloom Fricke Xylenol Gel Phantom Performance for 3-D Conformal Radiotherapy using Multiple Radiation Fields

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Abstract— **The complex cancer treatment techniques require rigorous quality control. The Fricke xylenol gel (FXG) dosimeter has been studied to be applied as a three-dimensional (3-D) dosimeter since it is possible to produce 3-D FXG phantoms of various shapes and sizes. In this preliminary study the performance of the FXG spherical phantom developed at IPEN prepared using 270 Bloom gelatin from porcine skin made in Brazil was evaluated using MRI technique, aiming to use this phantom to 3-D Conformal Radiotherapy (3DCRT) with multiple radiation fields and clinical photon beams. The obtained results indicates that for all MR images of the FXG phantom irradiated with 6 MV clinical photon beam can be observed clearly the target volume and in the case of coronal image can also be observed the radiation beam projection and the overlap of different radiation fields used. The Fricke xylenol gel phantom presented satisfactory results for 3-D Conformal Radiotherapy and clinical photon beams in this preliminary study. These results encourage the additional tests using complex treatment techniques and they indicate the viability of applying the phantom studied for routine quality control measurements and in 3DCRT and intensity modulated radiotherapy (IMRT) treatment planning.**

Keywords— **Fricke xylenol gel phantom, 3-D conformal radiotherapy, multiple radiation fields, clinical photon beams.**

I. Introduction

The sophisticated tumor treatments such as three-dimensional (3-D) conformal radiotherapy (3DCRT) and intensity modulated radiotherapy (IMRT) have grown in use during the last few years because they have advantages over conventional radiation treatments techniques since allow the delivery of a higher tumor dose while maintaining an acceptable level of normal tissue complications. Before performing these radiation treatments is achieved a 3-D target localization using computed tomography (CT) scans, for example, and 3-D treatment planning to differentiate accurately between tumor and healthy tissue [1, 2].

Because these complex treatment techniques the quality control (QC) must be strict and one dosimetric system that has been studied [3-5] for QC application in these cases is the Fricke xylenol gel (FXG) dosimeter since it is possible to produce 3-D FXG phantoms of various shapes and sizes. The dosimetric principle of the FXG solution is the oxidation of ferrous ions (Fe^{2+}) originally present in a non-irradiated solution, to ferric ions (Fe^{3+}) which results from the action of ionizing radiation in aqueous solutions [6].

In this preliminary study was verified the performance of the FXG phantom developed at IPEN prepared using 270 Bloom gelatin from porcine skin made in Brazil for 3DCRT using multiple static radiation fields and clinical photon beams. In a future work this dosimeter will be evaluated using the IMRT technique and 3DCRT additional tests will also be performed.

II. Materials and methods

The FXG phantom and FXG samples for dose-response curves obtaining were prepared at High Doses Laboratory (LDA) of IPEN. The gamma and photon irradiations were performed in the Radiotherapy Service and the dose evaluations were performed in the Resonance Magnetic Service at Diagnostic Image Department of the Sao Paulo Hospital (HSP), Federal University of Sao Paulo (UNIFESP).

A. FXG phantom preparation

A spherical glass flask of 2000 mL with 158.0 mm diameter with one short neck was completely filled with FXG solution prepared according to Olsson [7] using 5% by weight 270 Bloom gelatin from porcine skin, ultra-pure water and the following analytical grade reagents: 50 mM sulphuric acid (H_2SO_4), 1 mM sodium chloride (NaCl), 1 mM ferrous ammonium sulphate hexahydrate or Morh's salt [$Fe(NH_4)_2(SO_4)_2 \cdot 6H_2O$] and 0.1 mM xylenol orange ferric ions indicator ($C_{31}H_{28}N_2Na_4O_{13}S$).

The FXG phantom was maintained under low temperature and light protected during 12:30 h after preparation.

B. FXG samples preparation

Polymethylmethacrylate (PMMA) cuvettes with parallel optical faces measuring 10 x 10 x 45 mm^3 and path length of 10 mm were filled with FXG solution in order to obtain the magnetic resonance (MR) signal intensity in function of absorbed dose (dose-response curve).

C. Treatment planning

Computed tomography scans were obtained from an identical spherical glass flask used to FXG phantom preparation, in this case completely filled with tri-distilled water, using a PHILIPS® Brilliance CT 64-channel scanner (HSP/UNIFESP). The 3-D treatment planning was performed using the ECLIPSE® External Beam Planning system version 7.3.10. Multiple static radiation fields were used and the irradiation parameters are presented in Table 1.

Table 1 Irradiation parameters for the FXG phantom

Radiation Field	Gantry Position (°)	Treatment Couch Position (°)	Field Size (cm)				SSD (cm)	Monitor Unit (MU)
			X1	X2	Y1	Y2		
1	210.0	0.0	+3.45	+3.45	+2.5	+3.0	91.9	1731
2	30.0	0.0	+3.5	+3.5	+2.5	+3.0	91.9	1882
3	120.0	350.0	+4.0	+4.5	+2.5	+3.5	91.9	1661

D. Irradiation

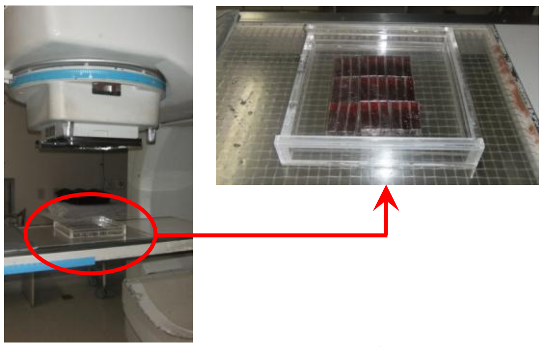
FXG samples irradiation: Three FXG samples sets were prepared in order to obtain the arithmetic mean of three measurements. Each samples set was packed with polyvinyl chloride (PVC) film in order to avoid contact of the FXG solution with tri-distilled water of the water phantom used to samples irradiation.

The FXG sample sets were maintained for approximately 30 min at room temperature and light protected before irradiation. The FXG samples were irradiated with absorbed doses between 2 and 20 Gy, dose rate of 74.98 cGy.min^{-1}, 40 x 40 cm^2 field size, source-surface distance (SSD) of 80 cm and 0.5 cm PMMA build-up thickness, using a GENERAL ELECTRIC COMPANY® Alcyon II ^{60}Co gamma radiation (HSP/UNIFESP) and a water phantom [PMMA 22 x 22 x 10 cm^3 filled with tri-distilled water].

The experimental set up for FXG samples irradiation with ^{60}Co gamma radiation is presented in Fig. 1. All FXG sample sets were positioned together in the water phantom (Fig. 1b) and each set was removed when the radiation exposure time needed to obtain the desired absorbed dose was completed.

FXG phantom irradiation: The FXG phantom was positioned in a Styrofoam box containing ice cubes in order to maintain the phantom under low temperature and light protected to be transported to the irradiation site. The phantom was removed of the Styrofoam box and maintained during 30 min at room temperature and light protected before irradiation. The FXG phantom was housed in a foam backer to be irradiated with 6 MV clinical photon beams with absorbed dose of 20 Gy and dose rate of 300 cGy.min^{-1} using a VARIAN® Clinac 600C linear accelerator (HSP/UNIFESP). A Cerrobend® shielding block with shape simulating a bladder tumor inside the phantom was used. Other irradiation parameters are presented in Table 1.

The experimental set up for FXG spherical phantom irradiation with clinical photon beams is presented in Fig. 2.



a b

Fig. 1 Experimental set up for FXG samples irradiation with ^{60}Co gamma radiation (a) and FXG sample sets positioned in water phantom (b)

Fig. 2 Experimental set up for FXG spherical phantom irradiation with 6 MV clinical photon beams using a Clinac 600C linear accelerator

E. Evaluation

The evaluation technique employed was the magnetic resonance imaging (MRI) using a SIEMENS® MAGNETOM® Sonata Maestro Class 1.5 T MRI scanner (HSP/UNIFESP). The MRI scans of the FXG solution were obtained on cranium protocol-T1 approximately 30 min after irradiation. The MR images acquisition parameters are presented in Table 2.

Table 2 MR images acquisition parameters

Image Orientation	Coronal, sagittal and axial
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 (º)	15
Matrix Size (MS) (pixels)	256 x 256
Number of Signals Averaged (NSA)	1
Slices Number	176
Coil	Head
Channels	8

The softwares syngo fastView® version VX57F24 and ImageJ® version 1.42q were used to process the MRI scans obtained.

III. Results

A. Dose-response curve

The MR images (coronal orientation) of the PMMA cuvettes filled with FXG solution irradiated with ^{60}Co gamma radiation (dose range from 2 to 20 Gy) is presented in Fig. 3.

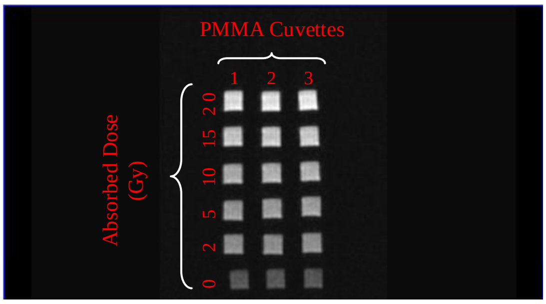


Fig. 3 Coronal MR images of the FXG solution conditioned in PMMA cuvettes and irradiated with ^{60}Co gamma radiation

The dose-response curve of MR signal intensity in function of absorbed dose obtained from the image presented in Fig. 3 is presented in Fig. 4. The background values corresponding to the MRI measurements of non-irradiated FXG samples were subtracted from all MR signal intensity values presented.

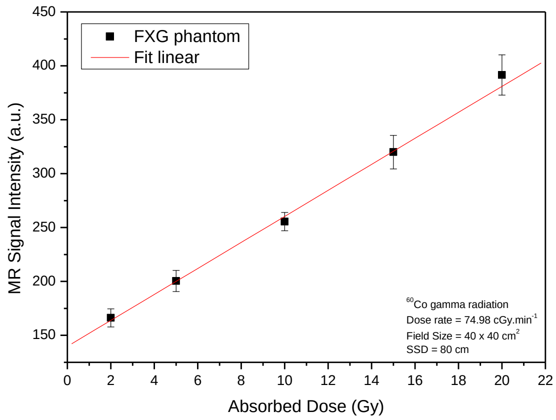
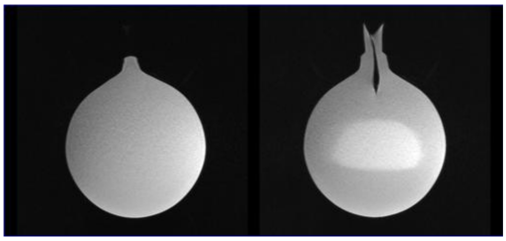


Fig. 4 MR signal intensity curve in function of absorbed dose of the FXG samples image

B. FXG phantom MR imaging

The MR images of the FXG phantom non-irradiated and irradiated with 6 MV photons are presented in Fig. 5. MR slices in different orientations of the FXG irradiated phantom is presented in Fig. 6.

Isodose curves and 3-D reconstruction showing the multiple static radiation fields of the FXG spherical phantom irradiated with 6 MV photons are presented in Figs. 7 and 8, respectively.



a b

Fig. 5 Sagittal MR images of the FXG phantom non-irradiated (a) and irradiated (b) with 6 MV photons

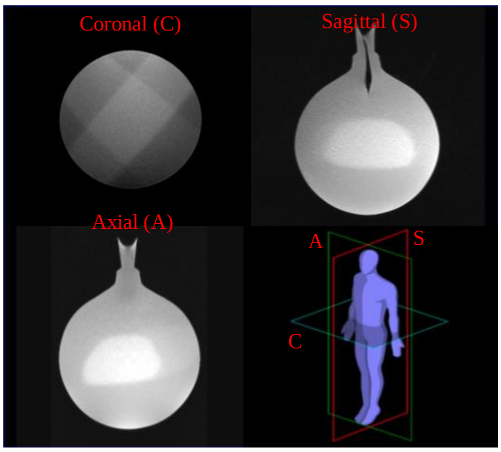


Fig. 6 Coronal, sagittal and axial MR slices of the FXG phantom irradiated with 6 MV photons

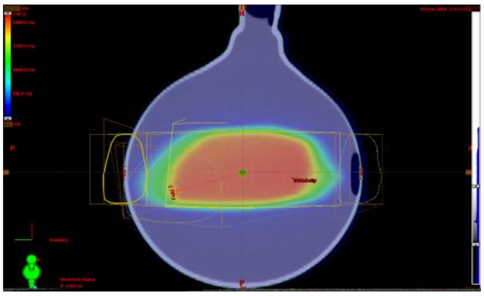


Fig. 7 Isodose curves of FXG phantom irradiated with 6 MV photons (sagittal Eclipse® image)

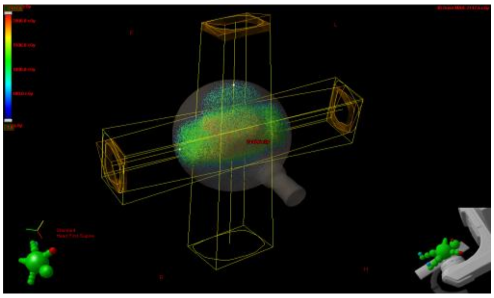


Fig. 8 Three-dimensional reconstruction of the target volume irradiated showing multiple fields used (Eclipse®)

IV. Discussion

The MR signal intensity in function of absorbed dose in the radiotherapy dose range interest presents linear behavior.

The obtained results indicates that for all MR images of the FXG spherical phantom irradiated with 6 MV clinical photon beams can be observed clearly the target volume and in coronal image (Fig. 6) can also be observed the radiation beams projection and the overlap of different radiation fields used.

V. Conclusions

The Fricke xylenol gel phantom prepared with 270 Bloom gelatin from porcine skin made in Brazil presented satisfactory results for 3-D Conformal Radiotherapy and clinical photon beams in this preliminary study. These results encourage the additional tests using complex treatment techniques and they indicate the viability of applying the phantom studied for routine quality control measurements and in 3DCRT and IMRT treatment planning.

Acknowledgments

The authors are grateful to the staffs of the Radiotherapy Service and Resonance Magnetic Service of the Diagnostic Image Department of the HSP/UNIFESP to allow the FXG irradiations and MR evaluations, respectively, and CAPES, CNPq, IPEN and CNEN by the financial support.

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