3D Dose Distribution Evaluation for Stereotactic Radiosurgery using MRI Images of Fricke Xylenol Gel Phantom

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Abstract. To avoid radiation damage to the surrounding normal tissues during treatment of the intra-cranial lesions using the stereotactic radiosurgery (SRS) is necessary to ensure reliable and accurate performance of the radiosurgical procedure. The Fricke xylenol gel (FXG) dosimeter can be applied in quality control of SRS because is able to be performed on different shapes and sizes. Aiming to verify the 3D dose distribution in linear accelerator (Linac)-based stereotactic radiosurgery, in this study were evaluated magnetic resonance imaging (MRI) images of the FXG spherical phantom prepared with 270 Bloom gelatin from porcine skin (made in Brazil). The good results obtained in this work indicate that FXG phantoms produced at IPEN can be applied for the quality control of the treatment planning of Linac-based stereotactic radiosurgery, using MRI technique.

1 Introduction

Stereotactic radiosurgery (SRS) is a well-established technique for treating a wide variety of intra-cranial lesions [1] by single session or fractionation of stereotactic dose delivery, depending on the disease treated, volume and location of the target [2]. Single session treatment employs prescribed doses of 12–25 Gy [2].

To avoid radiation damage to the surrounding normal tissues [1] the target localization, through treatment planning system to dose delivery, must be verified experimentally to ensure reliable and accurate performance of the radiosurgical procedure [2]. For this, a dosimetric system is required [2] and TLD, diodes, diamond detectors or small volume ion chambers have been performed, conventionally [3]. But, the dosimetric system should ideally be able to measure the dose distribution in three-dimensional (3D) space, since stereotactic radiosurgery can employ rather complicated 3D dose distributions [4].

The Fricke xylenol gel (FXG) dosimeter, whose principle is based in the oxidation of ferrous ions (Fe^{2+}) originally present in a non-irradiated solution, to ferric ions (Fe^{3+}) by action of ionizing radiation, is a promising tool to satisfy this requirement [5-8].

Aiming to verify the 3D dose distribution in linear accelerator (Linac)-based stereotactic radiosurgery, in this study were evaluated magnetic resonance imaging (MRI) images of the FXG spherical phantom prepared with 270 Bloom gelatin from porcine skin (made in Brazil).

2 Materials and Methods

2.1 Fricke Xylenol Gel Solution

The FXG solution was prepared at High Doses Laboratory (LDA) of IPEN according to Olsson [9], using 5% by weight 270 Bloom gelatin from porcine skin, ultra-pure water and the chemicals analytical grade following: 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 ferric ions indicator ($C_{31}H_{28}N_2Na_4O_{13}S$).

The solution was conditioned in polymethylmethacrylate (PMMA) cuvettes (10 x 10 x 45 mm^3) and in a spherical glass balloon of 1000 mL.

Sets of three FXG cuvettes each were prepared for the irradiations and measurements, in order to obtain the calibration curve. The 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 spherical glass balloon was filled with FXG solution in order to conform a FXG brain phantom. The neck of FXG spherical phantom too was packed with PVC film to avoid water evaporation.

The FXG cuvettes and phantom were maintained under low temperature ((4 ± 1) ºC) and light protected during 10 h before irradiation.

2.2 Treatment Planning

Three-dimensional dose distribution for the radiosurgical treatment was calculated and superimposed on to the FXG phantom target information through a treatment planning system (Fig. 1). Axial computed tomography (CT) scan was obtained from FXG spherical phantom, using a GENERAL ELECTRIC™ Lightspeed RT16 scanner. The 3D treatment planning was performed using the ECLIPSE™ Treatment Planning System version 8.6 (VARIAN™).

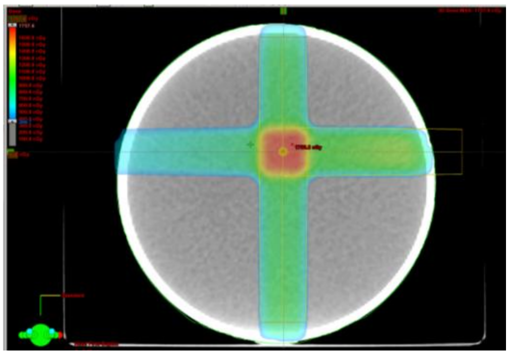
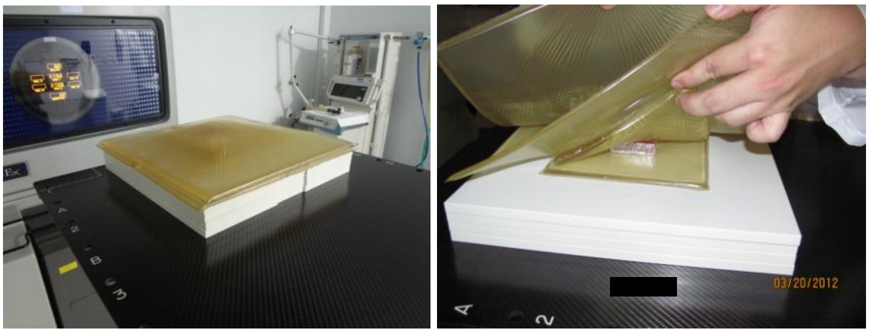


Fig. 1. Treatment planning using the axial CT scan from FXG spherical phantom (ECLIPSE™)

2.3 Irradiations

FXG Cuvettes. The FXG samples were irradiated with 6 MV photon beams, in the dose range of 2 to 20 Gy, dose rate of 600 $cGy.min^{-1}$, 15 x 15 cm^2 radiation field size, 2.5 cm thick bolus build-up, 0.5 cm thick bolus plus 4.0 cm thick solid water plates backscattering and source-surface distance (SSD) of 100 cm (in bolus surface), using a VARIAN™ Clinac 6EX linear accelerator. Each FXG cuvettes set was irradiated separately, according Fig. 2.



a **b**

Fig. 2. Experimental set up for FXG cuvettes irradiations (6 MV photons) (a); detailing the build-up (bolus) and backscattering (bolus + solid water) used in photon irradiations (b).

FXG Phantom. The FXG spherical phantom was irradiated, in single session, with 6 MV photons, with prescribed dose of 20 Gy to the target volume, dose rate of 600 $cGy.min^{-1}$, opposed and parallel [500 monitor units (MU) + 500 MU] and perpendicular (1000 MU) radiation fields, 2 x 2 cm^2 field size and SSD of 100 cm, using a VARIAN™ Clinac 6EX linear accelerator. The experimental set-up is presented in Fig. 3.

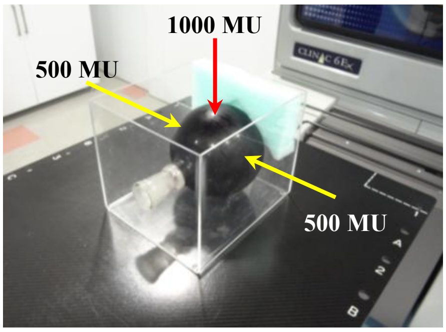


Fig. 3. Experimental set up for FXG spherical phantom irradiation (6 MV photons)

2.4 MRI Evaluation

The dosimetric response of the FXG cuvettes and phantom were evaluated employing MRI technique, using a GENERAL ELECTRIC™ Signa 1.5 T MRI scanner (Fig. 4).

a **b**

Fig. 4. Experimental set up for MRI images acquisition of the FXG cuvettes (a) and phantom (b)

The MRI images were acquired using T1-weighted spin-echo sequence and head coil, approximately 60 min after irradiation. The others MRI image acquisition parameters are presented in Table 1.

Table 1. MRI image acquisition parameters

Parameters Description	Values
Image Orientation	Coronal (cuvettes)/axial (phantom)
Field of View (FOV) (mm)	200
Slice Thickness (THK) (mm)	2.0
Voxel (mm)	1.04 x 1.04 x 1.0
Gap (mm)	0
Time of Repetition (TR) (ms)	700
Time of Echo (TE) (ms)	15
Flip Angle (º)	90
Matrix Size (MS) (pixels)	192 x 192
Number of Signals Averaged (NSA)	1
Slices Number	19 (cuvettes)/52 (phantom)
Reception Band (kHz)	15.6
Coil	Head
Channels	4

The PHILIPS™ DICOM Viewer R2.5L1-SP3 software was used to process the MRI scans obtained.

MATLAB scripts were used for identifying the information in the DICOM files, calibration curve fitting and isodose curves generation as a percentage of the dose to the central axis slices of MRI images.

3 Results and Discussions

Coronal MRI images of the FXG solution conditioned in PMMA cuvettes non-irradiated and irradiated with 6 MV photons (2 to 20 Gy) and axial MRI image of the FXG spherical phantom (6 MV photons and 20 Gy) are presented in Fig. 5.

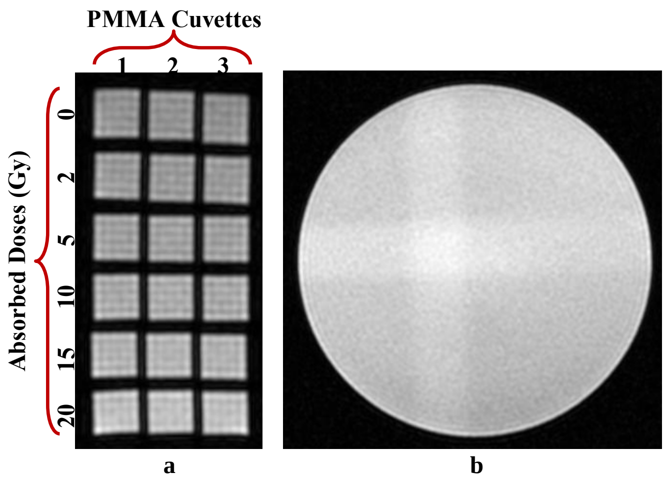


Fig. 5. Coronal MRI images of the FXG cuvettes (0 to 20 Gy) (a) and axial MRI image of the FXG phantom (20 Gy)

Observing Fig. 5a and 5b it can be seen good contrast between grayscale MRI images, being the pixels brightness proportional to the radiation dose (the higher the dose, the pixels are brighter).

The MRI signal intensity curve in function of absorbed dose (from Fig. 5a) is presented in Fig. 6. Each MRI value corresponds to the average of the region of interest (ROI) of three FXG cuvettes images and the error bars corresponds the uncertainties relating to ROI.

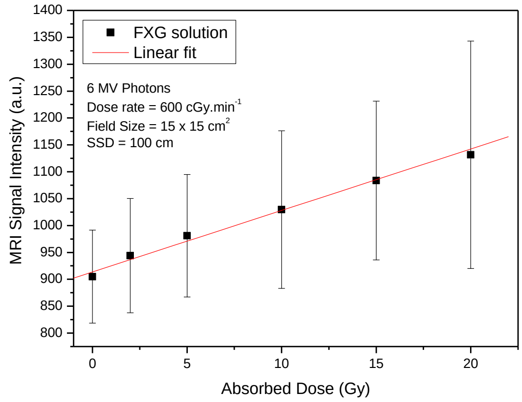
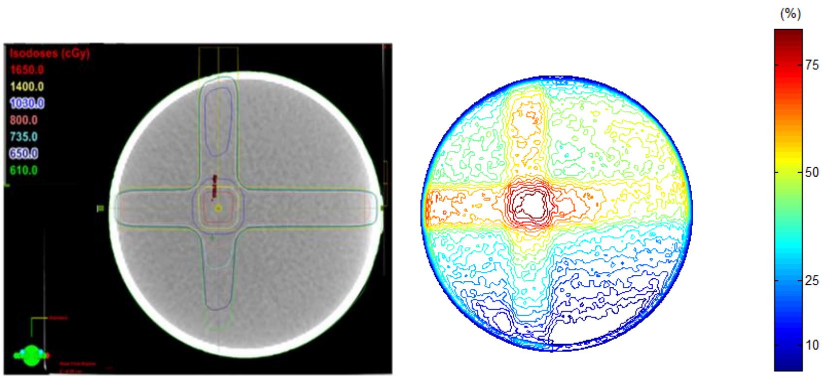


Fig. 6. MRI signal intensity curve in function of absorbed dose (6 MV photons)

The MRI signal intensity curve in function of absorbed dose (calibration curve) presented linear behavior in the clinical interest dose range (2 to 20 Gy) for MRI evaluation technique.

In Fig. 7 are presented isodose curves obtained using treatment planning system (Eclipse™), as well as experimentally, through of the MRI image of FXG spherical phantom irradiated with 6 MV photons (20 Gy in target volume).



a **b**

Fig. 7. Isodose curves obtained by treatment planning system (a) and experimentally (b)

Comparing the isodose curves determined from the MRI image of the FXG spherical phantom with those calculated by Eclipse™ system, can be seen that the irradiated target volume received the maximum dose, as expected.

In Fig. 8 is presented the 3D reconstruction of the FXG phantom images (6 MV photons; 20 Gy).

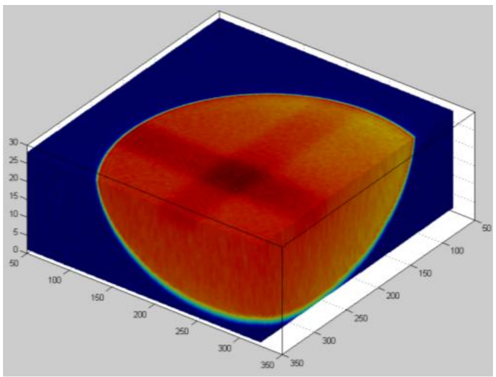


Fig. 8. Three-dimensional reconstruction of the irradiated FXG spherical phantom (6 MV photons and 20 Gy in target volume)

The irradiated target volume can be defined in the 3D reconstruction of the FXG phantom studied and can also be seen the input and the overlap of the different radiation fields used.

4 Conclusions

Good results were obtained in this work, which indicate that Fricke xylenol gel phantoms produced at IPEN can be applied for the quality control of the treatment planning of Linac-based stereotactic radiosurgery, employing the magnetic resonance imaging technique.

Acknowledgments

The authors are grateful to workers responsible by Radiotherapy Service and Resonance Magnetic Service of the Santa Catarina Hospital to allow the FXG irradiations and MRI evaluations, respectively, to physicist Eduardo Santana de Moura by your assistance when we request and to CAPES, FAPESP, CNPq, IPEN, CNEN, MCT: Project INCT for Radiation Metrology in Medicine and MRA Indústria de Equipamentos Eletrônicos Ltda. by the financial support.

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